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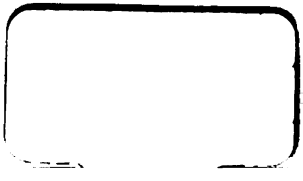

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CLIII.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cliii. p. 15, line 6 from bottom, *for* "Fig. 26" *read* "Fig. 25."
„ „ p. 22, „ 2 „ „ *for* "and" *read* "which."
„ „ p. 391, first line below Table, *for* "kilograms/centimetre" *read* "kilograms/square centimetre."

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THE
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SESSION 1902–1903.—PART III.

SECT. I—MINUTES OF PROCEEDINGS.

10 February, 1903.

JOHN CLARKE HAWKSHAW, M.A., President, in the Chair.

(Paper No. 3402.)

"The Manufacture and Efficiency of Armour-piercing Projectiles."

By DAVID CARNEGIE, Assoc. M. Inst. C.E.

WRITING, in 1880, on the true nature of the resistance of armour to shot, the late Mr. John Scott Russell, F.R.S., said:[1] "We began with the old cast-iron spherical shot, 8 inches in diameter, to which a 4½-inch plate offered effectual resistance. We next used a tough steel ball, of 10 inches diameter. These shot had sufficient power, and were fired with high enough velocity to do effectual damage to the ship's side if sufficiently often repeated; but the armour being improved, toughened, and thickened, prevented penetration." Since the period here referred to, the structure and material of the projectile have changed.

Round cast-iron shot were superseded by the Whitworth solid punching projectile. In 1862, Whitworth obtained a patent for armour-punching shells, which contained a bursting-charge: they were of steel, flat-headed, and rifled. In September, 1862, the *Warrior* target was completely punched at 600 yards by a Whitworth 130-lb. flat-headed shell.[2] In November, 1863, the first Palliser ogival-headed chilled-iron shot were tried at Shoeburyness.[3] This experiment marked a decided advance in the progress of projectiles.

DESIGN.

Figs. 1–4 represent the structure of the shot used for penetration up to that period. The modern armour-piercing projectile differs

[1] Transactions Institution of Naval Architects, vol. xxi., p. 84.
[2] Holley, "A Treatise on Ordnance and Armor," p. 182. New York, 1865.
[3] C. Orde Browne, "Armour and its attack by Artillery," p. 5. London, 1887.

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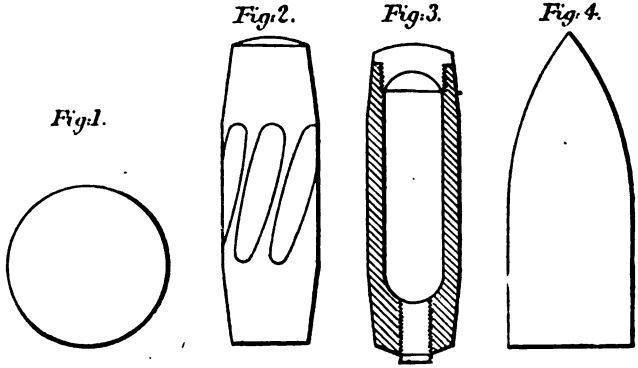
little in shape from *Fig. 4*. Many projectiles, with heads of different shapes, have been tried; but the ogival form has given the most satisfactory results, both at normal and at oblique firing. During the flight of the projectile the air offers less resistance to a head of this form than to any other.[1]

Since 1863 numerous designs have been brought out for armour-



piercing projectiles, differing in both form and material. *Figs. 5–22* are of interest as showing what has been attempted with a view to defeat armour in its onward progress. The last four of these (*19–22*) show designs of caps intended to overcome difficulties arising in oblique firing. It is questionable whether projectiles made to all the designs shown have been tested practically; and it would be interesting to know the penetrative effect of a projectile such as is shown in *Fig. 8*. It has been found that, the simpler the structure of an armour-piercing projectile, the more efficient it proves to be.

The most important part of the projectile is the head, and care must be taken that the cavity in it is so formed as to give a uniformly increasing section from point to shoulder. *Fig. 23* represents a 12-inch armour-piercing shell approved for the American sea-coast defence batteries in 1897, which differs only in detail from modern projectiles used at home and on the Continent. In the manufacture of the American shells "the manufacturer is left a free hand as to the chemical composition of the steel and its physical qualities, except that the Government inspector is to be kept fully informed as to the analyses and the results of physical tests."[2]

[1] Holley, "A Treatise on Ordnance and Armor," p. 536.
[2] *The Engineer*, vol. lxxxiv. p. 504.

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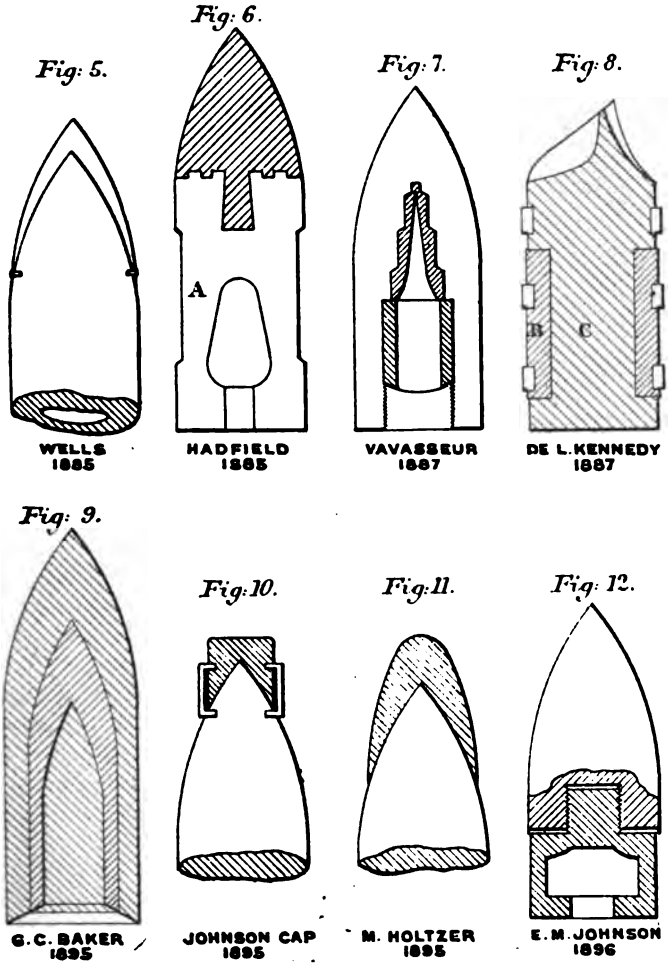

Fig. 5 shows, attached to head, a cap carrying a lubricant. *Fig. 6*, compound shot, the body A cast upon a hard steel point. *Fig. 7*, steel tempered shell with inner core; head made with an increasing radius of curvature towards point. *Fig. 8*, compound shot with a spiral-shaped chisel-point; body B free to turn on stem C. *Fig. 9*, compound armour-piercing projectile. *Fig. 10*, detachable soft-metal cap. *Fig. 11*, soft-metal cap. *Fig. 12*, compound shot with hard head and tough hollow body for explosives, separated by copper or leather washers.

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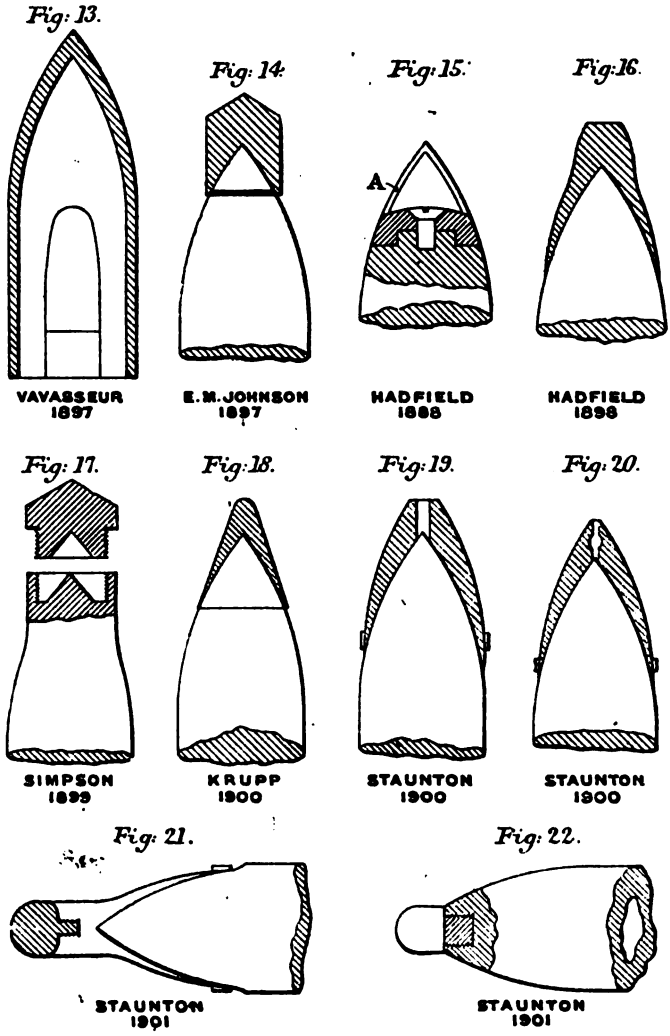

Fig. 13, hard-steel projectile, with iron or mild-steel jacket. *Fig. 14*, cap fitted round point of projectile. *Fig. 15*, cap fitted to cast-steel body, to which air-deflector A may or may not be attached. *Fig. 16*, soft-metal cap. *Fig. 17*, detachable cap. *Fig. 18*, soft-metal cap, so shaped as not to affect range of shell. *Figs. 19* and *20*, caps with cavities for lubricants. *Fig. 21*, compound cap, for use in oblique firing; point of cap made of wood, lead, aluminium, or like material; other portion of cap made of soft or hard steel; strengthening bands may be used for attachment of caps. *Fig. 22*, medium-hard steel point screwed into shell for oblique firing.

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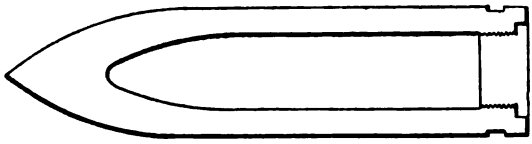
Material.

The material now used in the manufacture of shells is superior in quality to that used a few years ago. Until recently it was not possible to make cast-steel projectiles which could penetrate face-hardened steel. Improvements in the manufacture and treatment of steel have now rendered this possible; and great credit is

Fig. 23.



due to such men as the late Sir William Roberts-Austen, K.C.B., Messrs. R. A. Hadfield and J. E. Stead, Professor J. O. Arnold, and others in England, as well as to similar workers abroad, for their researches on alloys of steel, which have helped the manufacturer to produce castings having higher tenacity and corresponding toughness. The modern projectile is composed of steel containing carbon associated with one or more of the following metals: nickel, chromium, manganese and molybdenum. Mr. Hadfield has given [1] the following typical proportions of elements other than iron in shells which are air-hardened:—carbon 0·80 per cent., silicon 0·2 per cent., sulphur 0·04 per cent., phosphorus 0·04 per cent., manganese 0·12 per cent., nickel 2·00 per cent., chromium 2·00 per cent.

Manufacture.

Mr. Bruckner of the United States Navy says [2] truly that "the manufacture of shell is essentially an engineering problem"; he might have added, "particularly in the case of armour-piercing projectiles." Modern armour-piercing projectiles are made from either forgings or castings. It can no longer be said that it is impossible to make sound castings; and this fact has led manufacturers to take up the production of cast-steel projectiles, with the result that a much cheaper projectile can be made from the casting than from the forging; although the efficiency of forged projectiles still exceeds that of cast.

Projectiles which carry bursting-charges are, as a rule, called

[1] British Patent No. 6089 of 1901.

[2] *American Machinist*, 29th December, 1898.

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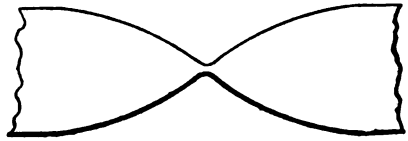
shell in order to distinguish them in name from those which do not, the latter being called shot.

Forging.—Shot are usually forged from ingots, of octagonal or circular section, one-and-a-half to one-and-a-quarter times the diameter of the finished projectile; and the ingots are cast of sufficient length to make either two projectiles or one, according to the method of manufacture. Ingots are usually removed from the moulds while hot, gradually re-heated, and then carefully forged under hydraulic pressure. It is essential that the power of the forging-press should be sufficient to produce uniform compression throughout the mass; and the Author calculates that the total

Fig. 24.

Fig. 25.



pressure in tons should be approximately between eight and ten times the number of square inches in the cross section of the ingot to be forged. One-half to two-thirds of the ingot can profitably be used; and when it has been reduced to a round bar slightly larger than the finished shot, the points are formed between swages and the forgings appear as shown in *Figs. 24* and *25*, according to the number of projectiles made from the ingot. They are then broken apart and annealed at a temperature of between 1,200° and 1,500° F., after which they are ready for machining.

Fig. 26.

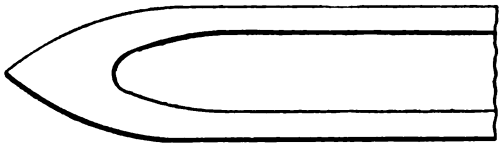
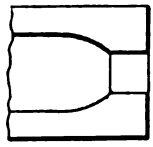


Fig. 27.



In the manufacture of forged armour-piercing shell with large cavities, the forgings, as shown in *Fig. 25*, are broken apart, and the cavity is formed by hydraulic pressure with suitable punches and dies. *Fig. 26* represents the shell punched. Where a small base-plug is used, the base of the shell is forged, as shown in *Fig. 27*, by being upset in a die while the base portion only of the shell is hot.

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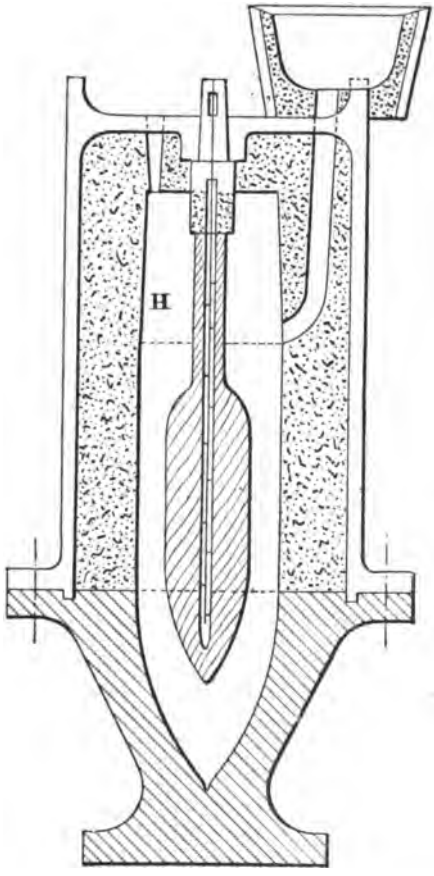
The forging increases the tenacity of the wall of a shell by between 20 per cent. and 30 per cent.; and the increase has been found by the Author to vary directly with the amount of work expended in forging.

Casting.—Cast-steel projectiles are moulded and cast in many ways. The object aimed at is soundness and homogeneity in the casting, so that the parts of unequal section may not, owing to irregular cooling, be unduly strained, and thereby rendered liable to crack after the projectile has been tempered and hardened. The method generally adopted is to cast the shell point downward, as shown in *Fig. 28*, in a similar way to that adopted in casting Palliser shell; but the sand composition is different. The body and deadhead of the projectile is cast in sand, and the point partially or wholly in a chill of iron. The mould is thoroughly dried, and the chill is heated and coated with a carbonaceous substance, in order to ensure a smooth surface on the casting. Chilling the point accelerates cooling where the cross-section is greatest, and thus prevents unsoundness at the bottom of the cavity. The head H (*Fig. 28*) also assists in feeding the body, and should be of such dimensions as to ensure soundness.

Fig. 28.



Mr. Hadfield has devised two methods of casting the points of

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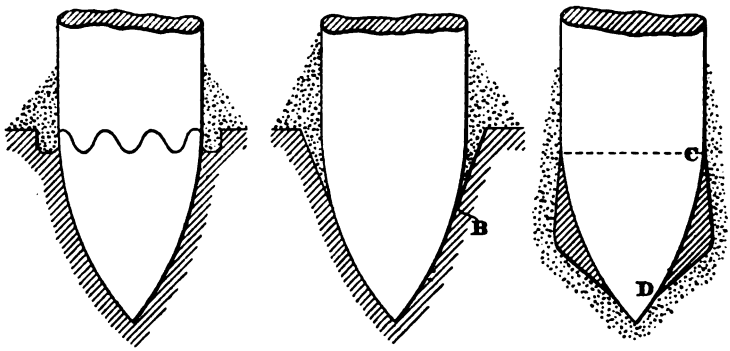
shells in chills. *Fig. 29* shows one method, wherein the chill extends from the point to the shoulder, round which the top of the chill is scalloped. In *Fig. 30* the chill extends to B, about half-way between the point and the shoulder, the remainder of the head being in sand, which gradually increases in thickness between B and the shoulder. If the unequal section of the head of a projectile be examined, it will be observed that the region of greatest heat usually lies between the points C and D in *Fig. 31*. Therefore, in order to produce uniform cooling, it is necessary to have the chilling influence greatest in the region of maximum heat: this may be done by a chill such as is shown in *Fig. 31*. It may perhaps be argued that any slight irregularity in the stresses set up by forced cooling is removed when the projectiles are annealed; and that the exact

Fig. 29. *Fig. 30.* *Fig. 31.*



shape of the chill is consequently not so important. It is doubtful, however, whether annealing eliminates entirely the distress produced in the head by forced irregular cooling; and there can be no doubt that annealing cannot remove the sponginess of the material at the bottom of the cavity, where irregular cooling takes place when the chill is not used. In 1893, Mr. R. Low devised a method of casting armour-piercing projectiles in a mould containing carbonaceous matter extending from the point to the shoulder of the shell, while the remainder of the body is in sand. When the shell has been cast, the mould and casting are placed in a furnace in order to produce surface-hardening by cementation; and the degree of carburization is proportional to the time the mould is kept in the furnace. The head is afterwards tempered by cooling in oil.

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Annealing.—This is a very important operation, the value of which is not generally known. Cast-steel projectiles are annealed in much the same way as forged-steel. A pile of castings is made on the hearth of the furnace, and the temperature is raised gradually and is maintained at between 1,200° and 1,500° F. for several hours, and sometimes days. It is then allowed to fall gradually, until the castings are sufficiently cool to be handled.

Machining.—For cast-steel armour-piercing projectiles the machining-operations are fewer, and, as a rule, less expensive, than for those of forged steel, because the formation of the cavity in the solid forging is a long operation. Other operations in both cast- and forged-steel projectiles are similar; but the cast-steel shell requires the additional operation of parting the deadhead from the base, after which the cavity is trimmed.

The body is turned, and the head is shaped to correct radius, either by cutting-tools or by grinding. The bases are faced, bored, and screwed for the base-plug, after which the fuse-hole is bored, screwed, and recessed in the plug. These operations are carried out in turret lathes. The groove for the driving-band is then formed; and the shell is adjusted to weight, stamped, and examined, before the hardening is done. In some projectiles the body is left a few hundredths of an inch large at the shoulder, until after hardening, when it is ground correctly to gauge.

Hardening.

Perhaps the most interesting and yet difficult process in the manufacture of projectiles for penetration is the hardening. Numerous methods are employed, many of which are kept secret by the manufacturers. Probably the earliest was that invented by Whitworth in 1862. In his specification [1] he states that he converts or highly carburizes a forged-steel bar of homogeneous iron or very mild steel ¼ inch to ½ inch deep, which then being dressed and bored, is put into the ordinary case-hardening material, heated to redness, and cooled by jets of water or brine. He then tempers it by placing its base on a block of metal heated to a dull red heat, until a straw colour at the point, and a blue colour at the base indicates that it is properly tempered. This is the method he adopted in hardening the armour-punching projectiles known as Whitworth projectiles; and in it can be seen the fundamental principles of many of the later processes for hardening both plates and projectiles.

[1] British Patent No. 1663 of 1862.

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In present methods of hardening three cooling-mediums are used, namely, water, oil and air. These differ in intensity of action, and the choice of the one to be used is determined by the composition of the material to be hardened. Moreover, each medium may be varied, water and oil in temperature, and air in pressure.

Carbon steels are, as a rule, hardened in water, or partly in water and partly in oil; nickel steels in water, or oil, or in air under pressure; chrome-nickel steels in oil, or in air under pressure; and steels having self-hardening properties are hardened by simply heating and allowing to cool in air. The degree of hardness obtained varies generally with the nature of the material, the temperature to which it is heated, and the rate of cooling. Glass-hardness or extreme softness can be produced respectively by suddenly quenching material in cold water from a high temperature, or by slowly cooling it, as in the process of annealing. Within this range of hardness, mysterious changes take place, about which little definite and reliable information has been obtained.

The principal operations in hardening projectiles are heating and cooling.

Heating.—Heating may be done in several ways, but should be gradual, as only the point and part of the body require to be heated. Sometimes the projectile is embedded in sand or fire-clay, leaving exposed to the heat the head only, which is heated gradually. In this way a large number of shells may be heated at one time. More often the heating is done in furnaces designed for the purpose. Mr. T. I. Tressider devised in 1897 a cylindrical furnace, in which the shell is heated while resting on its base: Mr. Hadfield has designed a cylindrical furnace heated by coke, in which the shell is suspended point downward. Gas-heating under air-pressure is perhaps more satisfactory and cleaner, and can be regulated better.

During the heating of the projectile, it can be raised and lowered in the furnace, in order to ascertain by inspection the colour and the intensity of the heating. When once the quenching-temperature has been determined by the colour test for any particular quality of steel, that temperature may be registered by the pyrometer, and uniform results may be obtained by the constant use of that instrument. The Callendar pyrometer, with which the Author is most familiar, is a simple instrument to use in the workshop, when it is shielded from sudden shocks or vibration. The quenching-temperature may range from 1,300° to 1,750° or 1,830° F., the correct temperature being determined practically. It would be useful to obtain,

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if possible, a table of hardness according to the quenching-temperature; and it might be expected that, with the same material quenched at different temperatures in the same cooling-medium, such a table could be obtained by ascertaining the compression, in tons per square inch, of test-pieces so treated. The Author has experimented with this object in view, but the results obtained have not shown a uniformly increasing hardness as the quenching-temperature is raised.

Cooling.—To plunge a hot projectile point downward into brine or cold water, and allow it to remain until cold, would be simply inviting destruction. A cooling-medium is selected which is suited to the nature of the material and the form of projectile to be hardened; and its action may be intensified by varying its temperature, or both its pressure and its temperature if it be air.

In deciding the proper medium in which a projectile should be hardened, chemical analysis and mechanical tests made on specimens from the wall of one of the projectiles, should be taken as a guide. Other minor tests serve as a guide in regulating the application and intensity of the cooling-medium, which are very important factors in successful hardening.

In 1897 Mr. Tressider devised a method of hardening projectiles by cooling them as they stood on their base, point upward, with a spray of water acting around and upon the hot head. A similar method is practised with the projectile point downward. Usually the water is allowed to act for only a few minutes both outside and inside the head, according to the size and nature of the projectile, which is afterwards toughened by immersion in oil.

Projectiles which are only oil-hardened are cooled gradually in oil-tanks by slowly lowering them point downward into the liquid, and, while doing so, changing their position in the tank. The oil may be kept cool by circulation through cooling-tanks.

Air-hardening is effected by directing a cold blast upon the inside and outside of the head of the projectile. Mr. Hadfield has recently introduced a method of hardening shells in this manner, cooling them from a higher temperature than is usually necessary for cooling in water or oil, and with less risk.

Another method of hardening projectiles which cannot be safely hardened in water without risk of fracture, is by placing the hot projectile point downward in a lining which fits the head, and is made of material of high conductivity, such as copper. By circulating cold water round the lining, without allowing it to come directly in contact with the projectile, heat is extracted rapidly from the head. The principal advantage of using such a lining is

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the possibility of varying its thickness from point to shoulder, and thus regulating the rate of cooling for any part of the head

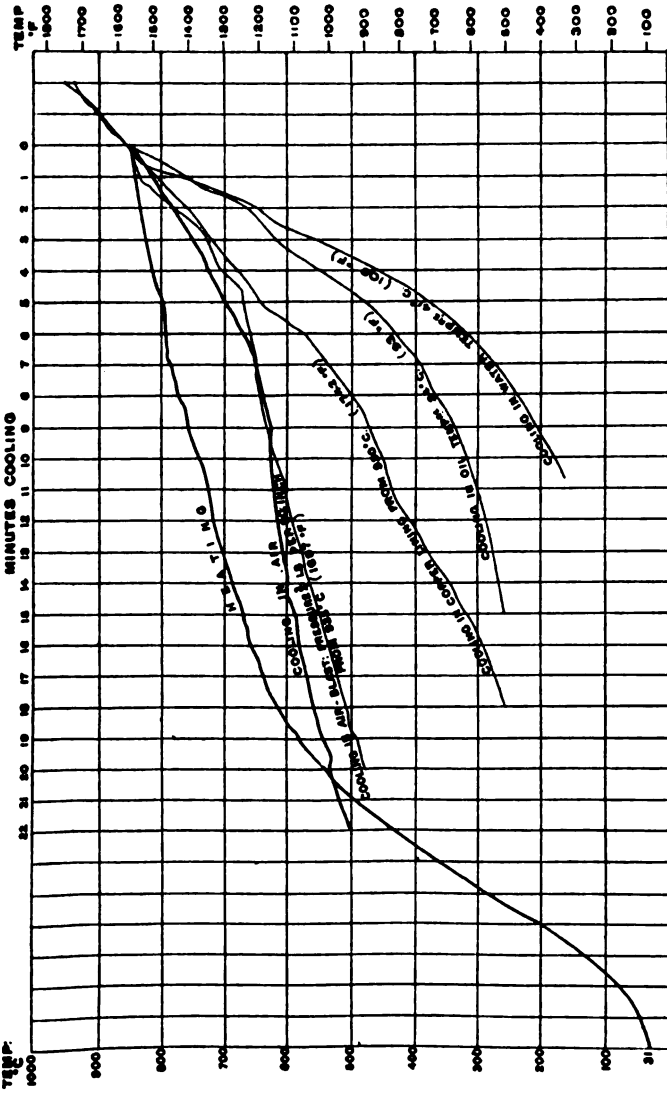
TEMP. F.
MINUTES COOLING
MINUTES HEATING
Cooling in water, 70deg F.
Cooling in oil, 70deg F.
Cooling in coarse sand from 600deg C.
Cooling in air, 20deg C.
Cooling in air from 600deg C.

Fig. 32. Cooling-Curves for Different Modes of Hardening Projectiles.

as desired: in this way the internal stresses are reduced to a minimum. The curves in *Fig. 32* show the rates of cooling in the

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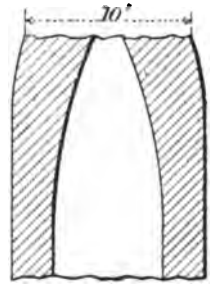
foregoing methods of hardening. The same projectile was used throughout the experiments, and the temperature was recorded by the Callendar pyrometer from the interior of the projectile.

Testing Projectiles after Hardening.—For the detection of initial strains bordering upon rupture in the projectile, it is laid down in the specification for American armour-piercing shells that "they must be cooled to a temperature of about 40° F. and then suddenly heated by being plunged into a bath of water at a temperature of 180° to 212°, as may be directed. When thoroughly heated to this temperature, each projectile must be plunged, with its axis horizontal, half-way into a bath of water at a temperature not greater than 40° F., and after a brief period will be turned 180° for a like immersion on the opposite side, after which the projectile will be removed from the bath." Further, "three days must elapse between the final treatment and this test."[1] They are also subjected to an internal hydraulic pressure of 500 lbs. per square inch. Similar tests are applied to English-made projectiles, and in addition they are kept in store for several months before they are finally accepted for service.

Fig 33.



The necessity for such tests is due to the unstable condition of projectiles for some time after hardening. The difficulty of detecting, by observation or by sounding, defects which may be concealed in the material, is very great; but such defects are often disclosed by hydraulic testing, or reveal themselves when the projectiles are kept in store for a time. It sometimes happens that, weeks or months after a projectile has been tested under hydraulic pressure, it cracks, and the head is thrown off violently from the body. In large projectiles the internal force producing rupture must be enormous. If, for instance, a 12-inch projectile cracks spontaneously through a horizontal cross section 10 inches in diameter and parallel with the base of the shell (*Fig. 33*), the ruptured surface has an area of about 75 square inches; and taking a low estimate of, say, 10 tons per square inch for the tenacity of the material at that section, it needs a total stress of 750 tons to rend the head. This example gives some idea of the unrest in the heads of hardened projectiles. To explain the cause is not easy; but from the

[1] *The Engineer*, vol. lxxxiv. p. 504.

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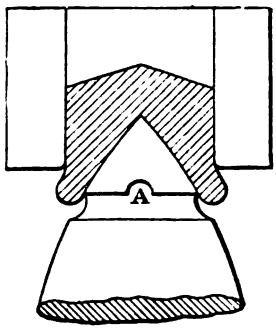
interesting experiment carried out by the late Sir William Roberts-Austen at the Institution[1]—showing the solidification of two transparent salts in solution, where crystals were formed separately and at different times during the cooling of the solution—some idea can be formed of what takes place during the cooling of steel projectiles, wherein different metals possessing distinct and definite properties are mixed.

Capped Projectiles.

The cap is always attached to the projectile after the latter has been hardened. Many methods have been devised for attaching special forms of caps already described under the design of shells: the Johnson cap which has come prominently into notice is pressed into a groove, as shown in *Fig. 34*. A notch A is made, and into it part of the metal is pressed, which prevents the cap from turning. This means of attachment is simple and effective.

Fig. 34.



Efficiency.

A projectile's efficiency is proportional to its capacity to overcome, without injury to itself, the resistance offered by a plate to perforation. This depends not only upon its shape, material and energy, but also upon its direction in relation to the plate. A brief reference to the development of armour-plates, since the introduction of wrought-iron plates in 1860, will enable a better idea to be formed as to what is required of the projectile.

In 1876 Messrs. Schneider, of Le Creusot, introduced steel plates.

Then followed the compound steel-faced iron plate (Wilson, Sheffield).

In 1889 Messrs. Schneider made nickel-steel plates.

In 1889 Harvey face-hardened steel plates by the cementation process.

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[1] "James Forrest" Lecture, 1902; by Sir W. C. Roberts-Austen, K.C.B. Minutes of Proceedings Inst. C.E., vol. cl. p. 159.

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In 1891–2, at the St. Chamond works, chrome-nickel-steel plates were made.[1]

In 1893–4 Messrs. Krupp made face-hardened nickel-chrome-steel plates.

In the past year (1902) Messrs. Krupp have made face-hardened cast-steel plates, which they state "are practically equal to their face-hardened rolled plates."[2] The chief advantage of cast plates is that they can be applied in any form or shape that may be required.

These advances have made the resisting value of the modern plates equal to nearly three times that of the wrought-iron plates of 1860. It cannot be said that the efficiency of the projectile, even with the higher velocities now obtained, has increased in the same ratio.

Through the kindness of the late Mr. F. A. Krupp, the Author is able to give five photographs showing the progress made during the past 10 years by projectiles, in their attack on armour-plates.

Fig. 35, Plate 1, is from a photograph of a compound plate 15·74 inches thick. Two 12-inch chilled-iron and one forged-steel shot were fired at this plate on the 14th March, 1892, at Meppen. The chilled shot were wrecked without cracking the plate. The forged-steel projectile penetrated 19·65 inches, and severely cracked the plate, without injury to itself. The ratio K, between the striking-velocity recorded in this trial and the standard perforation velocity for an equal thickness of wrought-iron, is 1·17 : 1.

Fig. 36, Plate 1, is from a photograph of a rolled mild-nickel-steel plate 15·74 inches thick. This withstood four steel projectiles and one of chilled iron fired from a 12-inch gun on the 10th September, 1892, at Meppen. All the projectiles were broken. The iron shot was completely destroyed, and the steel projectiles were fractured just behind the shoulder. Their average penetration was 19·45 inches. The plate was uncracked. The ratio K is 1·28 : 1.

On the 17th January, 1894, an oil-hardened nickel-steel plate (Fig. 37), 7·87 inches thick, received, in the course of firing-trials, three rounds from an 8·26-inch gun, and two from a 5·9-inch gun. The third round from the 8·26-inch gun was broken up; all the other projectiles penetrated between 10·5 inches and 11 inches,

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[1] E. Delmas. "Progress in the manufacture of Armour Plates from 1889," Mémoires de la Société des Ingénieurs Civils de France, 1900, Part 2, p. 320, and Minutes of Proceedings Inst. C.E., vol. cxliv. p. 370.

[2] *Engineering*, vol. lxxiii. p. 775.

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and rebounded 80 feet to 125 feet, unbroken. The ratio K is 1·28 : 1.

Fig. 38 is from a photograph of one of the first face-hardened nickel-chrome-steel plates made by Messrs. Krupp. The plate was 11·81 inches thick, and withstood three forged-steel projectiles from a 12-inch gun fired at Meppen on the 16th March, 1895, and two 9·45-inch forged-steel projectiles fired on the 3rd February, 1897. All the projectiles were completely wrecked, leaving their points embedded in the plate. The third round of the 12-inch gun weighed 715 lbs., and had a striking velocity of 2,000 feet per second, but the penetration was only 6·7 inches. The ratio K equals 1·81 : 1. The penetration of the fourth and fifth rounds of the 9·45-inch projectile could not be measured. The ratio K equals 1·98 : 1.

On the 2nd April, 1902, a face-hardened nickel-chrome-steel cast plate received five shots from a 5·9-inch gun fired at Meppen. Fig. 39 is from a photograph of the plate, and shows that the forged-steel shot, which weighed 112·404 lbs., and had striking-velocities ranging from 1,762 feet to 1,896 feet per second, were completely broken without cracking the plate. Their penetrations ranged from only 1·37 inch to 2·36 inches. The ratio K ranges from 1·61 : 1 to 1·8 : 1.

From the brief summary of these results given in Table I. extending over 10 years, it will be seen that, while the velocities have increased, the projectile has spent more of its energy in breaking itself than in penetrating the armour. The figures in the column headed K give the ratio between the striking-velocity in the firing-trials and the perforation velocity for an equal thickness of wrought iron, calculated on the basis of the Jacob de Marre formula.

While K shows an increase from 1·17 : 1 to 1·8 : 1 in 10 years, this is hardly a true indication of the increase of resistance offered by the plate. The velocity of the projectile which penetrated the compound plate 19·65 inches was 1·17 times that required to perforate 15·74 inches of iron. The velocity of the shot which penetrated the nickel-chrome-steel face-hardened cast plate 2·3 inches was 1·8 times that required to perforate 5·9 inches of iron. It was stated that 15·1 inches of iron could have been perforated by the round whose velocity-ratio was 1·8: so that the resistance of the plate was 2·56 times that of an iron plate 5·9 inches thick.

On comparing the above results with those obtained from plates made by Messrs. Schneider & Co. during practically the same

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period, it appears that an almost equal advance has been made in the resistance offered by their plates. Writing in 1898 Mr. Delmas said, "For plates attacked by 12·6-inch guns, the relative velocity imposed is 1·12 in 1893, 1·51 in 1894, 1·56 in 1897, and 1·66 in 1898. So from these figures the result is, for example, that of two plates of the same thickness attacked by 9·45-inch guns, one made in 1889 and the other of recent manufacture, the latter resists an attacking velocity superior by 55 per cent. to the attacking velocity of the former."

The above velocity-ratios are in relation to a unit velocity, determined by Colonel Jacob de Marre from actual trials by firing steel projectiles at homogeneous steel plates made in the works of Messrs. Schneider, and may be compared with K_2 in Table I., which is the ratio between the striking-velocity recorded in the trials and the standard perforation-velocity for an equal thickness of ordinary mild steel.

Figs. 40 and 41 are from photographs[1] of two armour-plates made by the Bethlehem Steel Co., and recently tested on the United States Government proving-grounds, with a view to the acceptance of groups of plates which they represented. The plates were not in any sense experimental, nor was their resistance overcome, as the illustrations show.

Fig. 40 is a 12-inch plate which received three 12-inch steel projectiles, each weighing 850 lbs., on the 24th September, 1901. The highest striking-velocity was 1,723 feet per second, and the energy of the projectile at the instant of impact was 17,514 foot-tons; the penetration was only 4·5 inches, wrecking the projectiles entirely without a crack in the plate.

Fig. 41 is a 6-inch plate fired at on the 27th March, 1902. The projectiles weighed 100 lbs. each, and had velocities ranging from 1,886 feet to 1,893 feet per second; the depth of penetration was between 1·1 inch and 1·6 inch, and all the projectiles were broken without cracking the plate.

It is therefore evident that in Germany, France, America, and, it may safely be said, in England, where the Krupp process is adopted by the principal firms, at normal impact an uncapped projectile cannot perforate a modern armour-plate whose thickness is equal to the diameter of the projectile.

Within the last few years an old practice has been revived, namely, that of fixing a soft-iron or steel cap to the point of the projectile, and thereby making it more efficient at normal impact.

[1] For these photographs the Author is indebted to the Bethlehem Steel Co.

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Russia is credited with having experimented with capped projectiles over a quarter of a century ago; and the Ordnance Department in this country tested and condemned capped projectiles in 1879. In 1894, public trials were carried out by Russia with an improved description of armour-piercing projectiles, which were facetiously described as magnetic.[1] Since then, many forms of caps have been tried, with a view to make the projectile more effective.

In some manner not yet fully explained, the cap favours the passage of the projectile through the hard face. It is supposed that the cap may break the cemented coating, and make bare the plate at the point of impact; but perhaps it is more effective at the instant of impact in diminishing somewhat the sudden violence of the blow, which tends to shatter the body of the projectile the moment it strikes the plate. It is thought by some that the cap acts as a lubricator, and that, by being driven before the projectile, it melts with the extreme heat generated, and hinders the hard cemented portions of the plate from scoring the head of the projectile, thereby diminishing the resistance to its passage. No doubt it protects and supports the point of the projectile, thus enabling it to penetrate more easily. Whatever may be the reason for the superior results of capped over uncapped projectiles, the fact remains that France, Russia, Germany and America have introduced them; and at home, as well as abroad, it has been found that the efficiency of the capped projectile considerably exceeds that of the uncapped. The recent trials of the Johnson capped shot and shell at Eskmeals on the 9th and 23rd May, 1902, have demonstrated beyond question the value of the capped projectile fired with normal impact.

Fig. 42, Plate 1, is from a photograph[2] of a 12-inch Vickers K. C. plate, which was attacked by Vickers 6-inch and 7·5-inch guns, with capped and with uncapped projectiles. The first three rounds were fired at this plate on the 9th, and two more rounds on the 23rd May, with the results given on p. 21.

Fig. 43 is from a photograph of a 6-inch Vickers K. C. plate, fired at on the 23rd May, 1902. Two 6-inch and one 7·5-inch projectiles were fired, particulars of which are given on p. 19.

These remarkable results clearly and convincingly prove the value of the capped projectile. Referring to the trials, *Engineering* says,[3] "With the 7·5-inch gun on these trials shells were used

[1] P. M. Staunton, *Engineering*, vol. lxxi. p. 336.

[2] For the originals of Figs. 42–44 the Author is indebted to Messrs. Vickers, Sons, and Maxim.

[3] Vol. lxxiii. p. 718.

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Round.	Projectiles.	Weight.	Striking-Velocity.	Striking-Energy.	Effect on Projectile.	Effect on Plate.
		Lbs.	Feet per Second.	Foot-Tons.		
1	Vickers 6-inch armour-piercing shot, fitted with Johnson cap .	105·0	2,799	5,705	Broken up	Completely perforated; no cracks.
2	Vickers 6-inch armour-piercing shot without cap	100·0	2,820	5,513	Broken up	Penetrated 3¾ inches; no cracks; point of shot fused in plate.
3	Vickers 7·5-inch armour-piercing shell with Johnson cap . . .	205·0	2,444	8,492	Broken up	Penetration 9½ inches (calculated).
4	Vickers 6-inch armour-piercing shot with Johnson cap . . .	105·5	2,786	5,676	Remained in backing	Completely perforated.
5	6-inch armour-piercing standard shot without cap . . .	100·0	2,827	5,542	Broken up; a large piece rebounded 20 feet in front of plate	Penetration 3 inches; point of shot fused in plate.

containing the equivalent of a 6-lb. bursting-charge, and these completely perforated the 6-inch modern cemented plate with a

Round.	Projectile.	Weight.	Striking-Velocity.	Striking-Energy.	Effect on Projectile.	Effect on Plate.
		Lbs.	Feet per Second.	Foot-Tons.		
1	6-inch armour-piercing shot (Vickers) without cap.	100	1,995·	2,766	Broken up	Not penetrated; signs of a bulge at back; no cracks.
2	7·5-inch armour-piercing shell fitted with Johnson cap.	205	2,186	6,795	Broken point, weighing 92 lbs., found in sand butt, 20 inches in rear of plate	Complete perforation; size of hole, 8·75 inches by 8·5 inches.
3	6-inch armour-piercing shot (Vickers) fitted with Johnson cap.	105	1,971	2,829	Broken up	Complete perforation; size of hole, 6½ inches in diameter.

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velocity corresponding to a range of 2,500 yards. It may be thus taken that such a gun using lyddite shell with a Johnson cap could perforate the water-line armour of all the battleships of the "Canopus" and "Duncan" classes, as well as all the armoured cruisers we are now building; making a very considerable hole, and causing much internal destruction."

Fig. 44 is from a photograph of a capped 6-inch armour-piercing shot which has passed through a 6-inch Krupp cemented plate; it shows the circular groove by which the cap is attached to the shell.

It is estimated that even with moderate velocities the projectile's penetrative effect is increased 30 per cent. by the use of the cap.

The Tables appended show at a glance the comparative value of capped and uncapped projectiles. Table II., for which the Author is indebted to Mr. John F. Meigs, Engineer of Ordnance to the Bethlehem Steel Co., U.S.A., shows the standard calculated perforations of armour-plate with normal impact at several ranges. Mr. Meigs says, "While this table of perforations is, of course, open to a little bit of doubt, from the variation of the quality of armour-plates and armour-piercing projectiles, yet, in our experience, it has usually been about correct. It is calculated from a considerable number of shots, covering wide range in thickness of armour-plate and in velocity of projectile."

Table III. is deduced from Table II., and shows the efficiency-ratio of capped and uncapped projectiles at the different ranges: it will be observed that there is little difference in the ratio at different ranges, and that the mean increase in perforation due to the use of the cap is 25 per cent.

Table IV. is also deduced from Table II., and shows the penetrative effect of capped and uncapped projectiles, measured in calibres, at the different velocities. As would be expected, the penetration increases with the velocity of the projectile, although $\frac{W}{D^3}$ does not vary much, W being the weight of the projectile in pounds and D its diameter in inches.

By the kindness of the late F. A. Krupp, the Author is enabled to give Table V., showing the penetrating capacity of armour-piercing projectiles. The figures, it is stated, are calculated on the basis of results actually obtained in experimental firing.

Table VI. is deduced from Table V., for comparison with the American standard (Table IV.).

All these Tables, however, relate to firing at normal impact. So

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far as is known at present, the capped projectile is no more efficient than the uncapped at oblique impact; and since it has been estimated[1] that "out of every ten shots fired from a moving ship at sea, about two may be expected to hit a ship at rest," and that "of those two shots that hit the stationary hostile ship but a very small proportion—a decimal proportion—will be found to strike the side at right angles," the importance of improving armour-piercing projectiles in order to increase their efficiency at oblique impact cannot be over-estimated.

The Paper is accompanied by two tracings and ten photographs, from which Plate 1 and the Figures in the text have been prepared.

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[1] Transactions Institution of Naval Architects, vol. xviii. p. 132.

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APPENDIX.

TABLE I.—RESULTS OF FIRING-TRIALS AT MEPPEN, SHOWING 10 YEARS' PROGRESS OF PROJECTILES IN THEIR ATTACK UPON ARMOUR-PLATES. (See Plate 1.)

Nature of Plate.	Thickness of Plate.	Date when fired at.	K.	K_2.	Effect on Projectile.	Effect on Plate.
	Inches.					
Compound steel and iron	15·74	14 March, 1892	1·17	0·91	Iron shot wrecked, steel shot whole.	Severely cracked by steel projectile. Penetration, 19·55 inches. (Fig. 35.)
Nickel steel, rolled .	15·74	10 September, 1892	1·28	1·00	Iron shot wrecked, steel shot broken behind shoulder	Plate uncracked. Penetration, 19·45 inches. (Fig. 36.)
Nickel steel, oil-hardened	7·87	17 January, 1894	1·24	1·00	Steel projectiles, four whole and rebounded, one broken up . .	Plate uncracked. Penetration, 11 inches. (Fig. 37.)
Nickel-chrome-steel, face-hardened . .	11·81	16 March, 1895	1·81	1·44	Steel projectiles all completely broken . . .	Plate had a few surface cracks only. Penetration, 6·7 inches. (Fig. 38.)
		3 February, 1897	1·98	1·57		
Nickel-chrome-steel, face-hardened cast plate	5·9	2 April, 1902	1·67 to 1·8	1·37 to 1·47	Steel projectiles all completely broken . . .	Plate uncracked. Penetration, 1·37 inches to 2·3 inches. (Fig. 39.)

The figures in the column headed K and K_2 are the ratios between the striking-velocity recorded in the firing-trials and the perforation-velocity for an equal thickness of wrought-iron (K) or ordinary steel (K_2) calculated on the basis of the Jacob de Marre formula.

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TABLE II.—PERFORATION OF STANDARD FACE-HARDENED ARMOUR BY CAPPED AND UNCAPPED ARMOUR-PIERCING PROJECTILES, AT NORMAL IMPACT. (BETHLEHEM STEEL WORKS.)

Projectile.		Perforation at Muzzle.			Perforation at 1,000 Yards.			Perforation at 2,000 Yards.			Perforation at 3,000 Yards.		
Calibre.	Weight.	Velocity.	Capped.	Uncapped.	Remaining Velocity.	Capped.	Uncapped.	Remaining Velocity.	Capped.	Uncapped.	Remaining Velocity.	Capped.	Uncapped.
Inches.	Lbs.	Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.
3·0	13	2,800	4·4	3·6	2,130	3·1	2·6	1,620	2·2	1·8	1,240	1·6	1·2
4·0	32	2,900	6·4	5·6	2,380	5·2	4·4	1,955	4·0	3·4	1,605	3·2	2·6
4·7	45	2,800	7·2	6·2	2,307	5·6	4·8	1,900	4·4	3·7	1,566	3·5	2·8
5·0	60	2,900	8·4	6·6	2,460	6·7	5 6	2,085	5·5	4·7	1,770	4·6	4·6
6 0	100	2,900	10·9	7·3	2,525	8·8	6·8	2,185	7·2	6·0	1,895	5·9	5·2
7·0	165	2,900	13·2	10·5	2,580	11·4	8·9	2,295	9·7	7·6	2,040	8·3	6·5
8·0	250	2,800	15·0	12·1	2,530	13·2	10·4	2,090	11·7	9·1	2,070	10·3	7·9
10·0	500	2,800	20·0	17·1	2,585	18·3	15 0	2,390	16·5	13·5	2,210	15·0	11·5
12·0	850	2,800	25·0	21·7	2,620	23·0	19·4	2,450	21·2	17·9	2,295	19·5	16·2

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TABLE III.—RATIO OF PERFORATION BY CAPPED AND UNCAPPED PROJECTILES. (BETHLEHEM STEEL WORKS.)

Calibre (D).	Weight (W).	$\frac{W}{D^3}$	At Muzzle.		1,000 Yards.		2,000 Yards.		3,000 Yards.	
			Capped.	Uncapped.	Capped.	Uncapped.	Capped.	Uncapped.	Capped.	Uncapped.
Inches.	Lbs.									
3	13	0·482	1·22 :	1	1·19 :	1	1·22 :	1	1·33 :	1
4	32	0·5	1·14 :	1	1·18 :	1	1·175 :	1	1·23 :	1
4·7	45	0·433	1·16 :	1	1·165 :	1	1·19 :	1	1·25 :	1
5	60	0·48	1·27 :	1	1·2 :	1	1·17 :	1	1·1 :	1
6	100	0·464	1·5 :	1	1·295 :	1	1·2 :	1	1·135 :	1
7	165	0·481	1·255 :	1	1·28 :	1	1·28 :	1	1·28 :	1
8	250	0·49	1·24 :	1	1·27 :	1	1·285 :	1	1·305 :	1
10	500	0·5	1·17 :	1	1·22 :	1	1·22 :	1	1·3 :	1
12	850	0·492	1·15 :	1	1·85 :	1	1·85 :	1	1·2 :	1

TABLE IV.—PENETRATION BY CAPPED AND UNCAPPED PROJECTILES IN CALIBRES AT VARIOUS VELOCITIES.

Calibre.	Weight.	$\frac{W}{D^3}$	Velocity.	Penetration.		Velocity.	Penetration.		Velocity.	Penetration.		Velocity.	Penetration.	
				Capped.	Uncapped.		Capped.	Uncapped.		Capped.	Uncapped.		Capped.	Uncapped.
Inches.	Lbs.		Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.	Feet per Second.	Inches.	Inches.
3	13	0·482	2,800	1·4	1·2	2,130	1·032	0·867	1,620	0·734	0·6	1,240	0·533	0·4
4	32	0·5	2,900	1·6	1·4	2,380	1·3	1·1	1,955	1·0	0·85	1,605	0·8	0·65
4·7	45	0·433	2,800	1·5	1·32	2,307	1·19	1·04	1,900	0·94	0·787	1,566	0·745	0·595
5	60	0·48	2,900	1·68	1·32	2,460	1·34	1·12	2,085	1·1	0·94	1,770	0·92	0·92
6	100	0·464	2,900	1·82	1·215	2,525	1·465	1·135	2,185	1·2	1·00	1,895	0·985	0·87
7	165	0·481	2,900	1·735	1·4	2,580	1·52	1·185	2,295	1·29	1·01	2,040	1·101	0·87
8	250	0·49	2,800	1·88	1·515	2,530	1·65	1·3	2,090	1·465	1·14	2,070	1·29	0·99
10	500	0·5	2,800	2·00	1·71	2,585	1·83	1·5	2,390	1·65	1·35	2,210	1·5	1·15
12	850	0·492	2,800	2·08	1·81	2,620	1·92	1·62	2,450	1·765	1·575	2,295	1·625	1·35

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TABLE V.—PENETRATING CAPACITY OF CAPPED AND UNCAPPED ARMOUR-PIERCING SHELLS, AT NORMAL IMPACT.

Calculated from Results of Experimental Firing by the late F. A. Krupp.

Projectile.		Penetration at Muzzle. Inches.			Penetration at 1,000 Metres. Inches.			Penetration at 2,000 Metres. Inches.			Penetration at 3,000 Metres. Inches.		
Calibre.	Weight.	Wrought-Iron Plate.	Non-hardened Steel Plate.	Face-hardened Nickel Steel Plate.	Wrought-Iron Plate.	Non-hardened Steel Plate.	Face-hardened Nickel Steel Plate.	Wrought-Iron Plate.	Non-hardened Steel Plate.	Face-hardened Nickel Steel Plate.	Wrought-Iron Plate.	Non-hardened Steel Plate.	Face-hardened Nickel Steel Plate.
Inches.	Lbs.	Uncapped.	Uncapped.	Capped.	Uncapped.	Uncapped.	Capped.	Uncapped.	Uncapped.	Capped.	Uncapped.	Uncapped.	Capped.
7·5	188·0	18·05	12·3	7·25	15·4	10·52	6·48	13·1	9·0	5·85	11·2	7·65	5·22
7·5	235·4	18·05	12·3	7·25	15·88	10·88	6·6	13 9	9·52	6·1	12·15	8·38	5·58
8·26	248·6	20·00	13·6	8·00	17·35	11·85	7·25	14·95	10·3	6·6	12·85	8·92	5 96
8·26	308·0	20·00	13·6	8·00	17·75	12·15	7·37	15·7	10·8	6·85	13·85	9·6	6 35
11·00	594·0	30·5	21·1	11·68	27·4	19·1	10·92	24·8	17·3	10·15	22·2	14·55	9 4
11·00	759·0	30·5	21 1	11·68	28·1	19·45	11·1	25·8	17·9	10·4	23·6	16·4	9·77
12·00	770·0	35·6	24·625	13·4	32·4	22·5	12·45	29·4	20·6	11·7	26·7	18·75	10 9
12·00	979·0	35·6	24·625	13·4	32·8	22·8	12·55	30·2	21·2	11·9	27·9	19·7	11·3

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TABLE VI.—DEDUCED FROM TABLE II. FOR COMPARISON WITH AMERICAN STANDARD (TABLE IV).

Calibre (D).	Weight (W).	$\frac{W}{D^3}$	Muzzle Velocity.	Penetration in Calibres.		
				Wrought Iron.	Non-hardened Steel.	Face-hardened Nickel Steel.
Inches.	Lbs.		Feet per Second	Uncapped.	Uncapped.	Capped.
7·5	188·0	0·446	2,640	2·41	1·64	0·97
7·5	235·4	0·559	2,360			
8·26	248·6	0·442	2,660	2·42	1·64	0·97
8·26	308·0	0·546	2,390			
11	594	0·445	2,910	2·77	1·92	1·06
11	759	0·557	2,575			
12	770	0·445	3,020	2·97	2·06	1·115
12	979	0·566	2,680			

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Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his Paper, remarked that it treated of a subject which, perhaps, not many members might be able to discuss with advantage, but one in which all were interested. It was universally admitted that England depended on its Navy for defence, and the efficiency of the Navy depended on, among various things, the efficiency of armour-piercing projectiles. The President.

Colonel E. BAINBRIDGE, C.B., said that ever since his boyhood the battle had been raging between plates and projectiles. He had been connected with the subject of warlike stores in various positions for over 30 years, and had watched the battle carefully. At one time the plate had been in the ascendant; but 6 or 8 years ago, when the compound plate had been in vogue, the projectile had had the advantage. Like others, he, as head of the laboratory, had produced 6-inch shell which had had no difficulty in perforating 9-inch plate. That was no longer the case. The advent of Tressider, Krupp, and other hardened plates, had enabled the plate to hold the field for the moment; but he did not think the battle was ended yet; in fact he was not at all sure that he would see the end of it. There was just as much science brought to bear on the manufacture of the projectile as on the production of the plate; and he felt sure the battle would be fought out still longer, to the bitter end. Although the plate had had the advantage for some time, the capped projectile was now beginning to assert itself; and, although it was stated at the end of the Paper that the cap was effective only at direct impact, he was not sure that was quite correct. The Johnson cap seemed to be the most effective cap made at present, but it had one initial defect, namely, that it necessitated the formation of a groove round the point of the projectile, which must cause a tendency for the point to break off. If the cap could be fastened to the projectile without cutting into the point, the projectile would be stronger than one with a groove round it. The Author's remarks about cast-steel plates were new to him; he did not know that such a great advance had been made in economy, as well as in every other direction, by using that material. It was stated in the Paper that the Ordnance Department in England had tested and condemned Colonel Bainbridge.

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Colonel Bainbridge. capped projectiles in 1879. He thought the correct date was much later; and the conclusion come to had been that at which the Author seemed to have arrived now, namely, that capped projectiles were of use only for direct impact, whereas, as was pointed out in the Paper, only a very small proportion of the shots fired would strike a ship in action normally; nearly all the hits would be oblique.

Mr. Hadfield. Mr. R. A. HADFIELD considered that the Paper was an excellent summary of the present position of the armour-piercing projectile. He did not quite agree with the statement, on p. 5, that the forged projectile had greater efficiency than the cast; though as a maker of cast projectiles, he might be somewhat biassed in his opinion. Properly-made cast projectiles had proved themselves in every instance not only equal but superior to the best forged-steel projectiles; they were freer from the serious trouble of spontaneous fracture. It was essential that the projectiles used in ships of the Navy should not fracture in the powder-magazine. Many people held that something of that kind had occurred in connection with the destruction of the United States Ship "Maine," forged armour-piercing projectiles having been on board. Therefore, the production of a projectile which could be thoroughly relied upon on board ship was of the highest importance. With regard to the mysterious changes referred to at p. 10, he thought they were mysterious only because, until comparatively recently, they had not been studied properly. With experience, it was generally possible to say why a projectile had failed. Failure could not always be prevented; but when it occurred the cause could generally be traced, by means of the data obtained in carrying out the processes of manufacture. The question of spontaneous fracture was no doubt of great importance, but manufacturers were learning every day how to control it. It would be interesting if the Author could add a table of his compression tests to the Paper, as it would be advantageous to know something more on that point. The temperatures in *Fig. 32* had been taken from observations on the interior of the projectile: as the real cooling proceeded mainly from the exterior, it would have been interesting if observations of temperature at the outer surface could have been added. He understood from the Author, in reference to the curves in *Fig. 32*, that the projectile had been drilled internally, and that the figures really represented the temperature within about 2 inches of the point. That partly met his suggestion; but it would have been an advantage if the temperature at the outer surface had been given also. As a matter of historical interest,

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he believed the first cast projectile had been one fired by his firm at Shoeburyness as far back as June, 1884. English manufacturers were quite willing to accord credit to their American friends, but he thought it was only just it should be known that an English firm so far back as the date mentioned had successfully perforated an 8-inch wrought-iron plate with a 6-inch shot, unbroken. About 2 years later they had succeeded with a 9·2-inch solid shot in perforating about 18 inches of wrought iron, without breaking the shot. These, he thought, were remarkable results for that time. The question of caps was no doubt highly important; but the ordinary literature of the subject ignored the fact that, while capped shot had given good results, capped shell—that was, armour-piercing projectiles having a bursting-capacity of 4½ to 5½ per cent.—had so far not been proved to possess the advantage claimed for them. In discussing the question it was important to bear in mind the distinction between shot and shell. Shot had an internal bursting-capacity of not more than about 2 per cent., and he believed that in the Navy they were seldom or never charged with explosives. In shell the bursting-capacity was usually about 5 per cent. Obviously, it was impossible to expect the same result, even with a cap, from a projectile which, owing to its greater internal capacity, had a comparatively weak head. He drew special attention to that point because the "man in the street" who read glowing descriptions of the wonderful results of capped shot, said at once: "Why are they not adopted in the British Navy?" But the War Office, the Admiralty, and the Ordnance Committee had wisely demanded more evidence of their advantages. The tests made so far with capped shell had shown that caps were of little service in helping perforation with armour-piercing shell—unless the plate was comparatively thin, in which case the uncapped shell would do as well, if not better. If a 6-inch shell was fired at a 3-inch plate, perforation naturally occurred; but, as would be seen from the Paper, shot were usually fired at plate equal or superior in thickness to the calibre of the projectile; and under these conditions a weak projectile with a larger internal bursting-capacity could not be expected to give the same results. As there were about fifty armour-piercing shells used in the Service to one shot, he thought the authorities had acted wisely in taking time before introducing a new method. With regard to shot, his own firm, on the 15th December, 1898, had fired at Shoeburyness several 4·7-inch capped shot, and had been able, with a velocity of about 2,300 feet per second, to

Mr. Hadfield.

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Mr. Hadfield. perforate a 6-inch hard-faced plate inclined 20°. This was he believed the first successful capped shot fired in England against hard-faced modern armour. The plate, although not of the present type, had been a cemented one, made by a well-known Sheffield firm, and had previously resisted 6-inch shot fired with lower velocity. It seemed somewhat strange that nearly all foreign governments had largely ignored the fact that in warfare projectiles must strike obliquely rather than normally, and had made their tests with normal impact, which considerably favoured the cap. The British government, on the contrary, had wisely made important tests obliquely, and, with some exceptions, the results had not been as promising. He thought a great debt was due to the Ordnance Committee, of which Sir Benjamin Baker was a member, for having exercised great caution before deciding whether to adopt into the Service any method of capping projectiles. He had placed on the table a few specimens, including a 4½-inch calibre shot ready for capping, and another shot of the same size with the cap on. One of the shot shown had passed unbroken through a 5-inch ordinary steel plate. The remains of a shot of the same calibre fired against a 5-inch Krupp-cemented plate with a velocity of about 2,050 feet per second, and only penetrating about 1½ inch, were also on the table. Those rounds had been fired at the Hecla Works at Sheffield, and the destruction of the uncapped shot was evident. A capped shot of the same size had been fired again at the same plate, with a velocity of about 1,940 feet per second, and the whole of it had been recovered on the other side of the plate, a portion in a broken condition, but the point perfect. He also exhibited a number of points of capped shot which had been subjected to a similar test, and it was remarkable how exceedingly sharp were the points after having passed through a hard-faced plate: whereas an uncapped shot under similar circumstances was absolutely wrecked. In order to show what the possible effect of the impact might be on the cap, he exhibited another loose cap which had been subjected to hydraulic pressure of 150 tons. No doubt it showed exactly what happened in actually firing a capped shot normally against a hard-faced plate. It would be seen that the sharp hard point was just beginning to appear through the cap, which proved that the cap did protect the point of the shot. Personally he agreed with the Author that it was rather a question of deadening the blow. He did not know that there was any marvellous efficacy in the cap, but it reduced the shock to the projectile, so that the latter was not inclined to shatter so quickly, and its point was protected,

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Lieutenant A. T. Dawson remarked that everything in the Paper was of the utmost interest to him, because he was concerned in the production of projectiles, especially capped projectiles. Mr. Hadfield had referred to the inexpediency at the present time of capping semi-armour-piercing shell. Perhaps that was right in regard to the application of the cap to the existing shell, but he could not agree as to not capping a proper armour-piercing shell. It was no use firing an armour-piercing shell against hard armour unless it was fitted with a cap, because it would not perforate the armour; it would simply glance off and do no harm. He considered the capping of shell, as well as of shot, to be of the highest importance. The French government were using caps on all semi-armour-piercing shell, as well as on ordinary shell, because they found that the capped shell was very effective against a particular thickness of hardened thin armour. He thought that was the experience of all foreign governments, and with it he fully agreed. It was undoubtedly difficult to explain the action of the cap. Notwithstanding Mr. Hadfield's remarks, he doubted whether an experiment carried out by applying pressure slowly to a cap was likely in any way to be comparable with the action of a shot hitting a plate at a very high velocity, in which the time-element above everything was of the greatest importance. In his opinion the action of the cap was that when the projectile struck the plate, it dished it at the point of impact, and perhaps strained it nearly up to its elastic limit. The first thing to touch the plate was the cap; the point of the projectile had then to travel practically the length of the cap before it touched the plate; and when the point touched the plate, the latter was probably already strained beyond its elastic limit. That being so, the projectile had easy work in piercing the very hard surface of the plate: once the point had got in it was supported; and it only remained for the high energy contained in the projectile to do the necessary work of completing the perforation, if that energy was sufficient. As an example of the influence of the time-element, he might call attention to the effect of passing wire through rolls. If the rolls were run slowly no harm was done to them, and the wire was flattened. If, on the other hand, the rolls were run quickly, they were damaged; an impression was actually made on the surface of the steel rolls. That was a practical example of the effect of the time-element, and it indicated why the application of hydraulic pressure to a cap could not illustrate satisfactorily the action of the cap in practice. It was a matter of opinion, but he thought the explanation he had given was a practical one which would

Lieut. Dawson.

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Lieut. Dawson. appeal to engineers. Under normal attack, when the point of the projectile had penetrated into the plate, there was not the same tendency of the projectile to break up as in oblique firing. Once a hole was made in the hardened surface, the point was supported in the soft part of the plate at the back, and, provided it had the necessary energy, it passed through. Whether the shot passed through intact or broken up depended entirely upon the quality of the projectile. The quality of the material of the projectile was of paramount importance, because if the shell did not hold together, the bursting-charge did not get through; it simply exploded at the surface of the plate, or possibly on its way through. If the attack was oblique, at an angle of, say, 20°, then not only did the projectile have to penetrate the plate, but there was also a resultant force tending to break the body of the shell across. For shot or shell the best possible material should be used, and he disagreed with Mr. Hadfield's opinion that the best material was cast steel. He thought it was generally admitted that in forged steel the crystals were in a more satisfactory condition; forged projectiles were more uniform, and the manufacturer was likely to get better results in general work. At all events, that was the experience of Messrs. Vickers, Sons and Maxim with forgings for hydraulic mountings and other mechanism in which severe stresses had to be resisted, for which a steel was required which should be without fault during a life of many years. He thought the same requirement applied to armour-piercing shot or shell. In capped projectiles in particular, the quality of the projectile must be taken into consideration; and in order to get the best results the best possible projectile must be provided as well as the best cap. With regard to oblique impact, he had been present at some trials, the object of which had been to find out whether the cap was useful only for normal attack, or whether it was also useful for oblique attack. The experiments had been carried out with an inclination of as much as 20°, but in other reliable trials with which he was acquainted the inclination had been as much as 30°. He would, however, give only the results of the experiments of which he had personal knowledge. In the first instance, a 6-inch gun, firing a 100-lb. shot, had attacked a 6-inch Krupp-cemented plate at an inclination of 20° to the normal. With a velocity of 2,097 feet per second, the uncapped projectile had done very little damage to the plate at that angle; it had penetrated it to the extent of 2½ inches, and had then been broken up, the whole of the projectile having been left in front of the plate. Had it been directed against the side of a ship, there would have been no material result.

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A capped projectile had been fired at the same inclination with a velocity of 2,107 feet per second. It had passed completely through, perforating the plate, the backing and the skin-plate; and in actual warfare it would have done a vast amount of damage. In another test at which he had been present, a 6-inch plate had been fired at normally with a 100-lb. projectile, at a velocity of 2,071 feet per second. That was a fairly high velocity for normal attack, but under those conditions the plate had not been perforated. The projectile had had no cap, and had penetrated to the extent of only 4 inches. At the same trials the same plate had been inclined at 20°, and fired at with a capped projectile at a velocity of 2,097 feet per second, and then the plate had been completely perforated. He believed those tests represented the actual effect of attack on a plate at an inclination of 20°. In another trial, conducted in America, a Carnegie-Harveyized nickel-steel plate, not Krupp cemented, had been fired at with a velocity of 2,100 feet per second. The capped shot had penetrated it completely, but the uncapped shot had not done so. Not only English manufacturers, but also important foreign countries, such as Germany, the United States, Russia and France, had all realized the importance of caps, and were capping to a large extent not only shot but also shell. With regard to the attachment of the Johnson cap to the ordinary armour-piercing shot or shell by means of a groove, it seemed at first sight that to put a circular groove round the point might weaken the shell; but experiments showed that it did not. The amount of metal removed was very small, being only sufficient to get a true mechanical fit, and proper means of holding the cap under the extreme strain of possible oblique attack on hard-faced armour. He had never found any weakness on that account, even when the projectile had gone through an exceedingly thick plate. By permission of Admiral Simpson, of the Chilian navy, he was allowed to give particulars of trials carried out recently at the Vickers works, wherein a 7-inch Krupp-cemented plate, picked from a large batch intended for the Chilian warship "Libertad," which was being built at Barrow-in-Furness, had been fired at normally. In the first place four shots had been fired with a velocity of about 2,100 feet per second, the velocity of the four not varying by more than 5 feet per second. Each of the shots had done practically immaterial damage to the plate, the maximum penetration having varied between 1 inch and 1½ inch, and the plate having been uncracked. He had then suggested firing a capped shot at the plate, and the suggestion having been concurred in, a capped shot had been fired, with exactly

Lieut. Dawson.

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Lieut. Dawson. the same velocity. This shot had completely penetrated the plate, the skin plate, and the backing, and had gone several feet into the sand-butt. That was a clear proof of the advantage of the cap at normal firing. With regard to the non-capping of shell, he had suggested to Admiral Simpson that a shell should be fired at the plate—which had done, perhaps, as well as any plate could have done—with a gun of a calibre as nearly equal to the thickness of the plate as was available. It had happened to be a 7½-inch gun. The projectile, weighing 200 lbs., had been fired at the same velocity as the 6-inch proof shot. It had contained a 6 lb. 12 oz. bursting-charge—a very good charge for a shell; the point of the shell had possessed sufficient strength and weight for the shell to go right through the plate-backing and skin-plate and the sand-butt behind, punching out from the back of the plate a large piece half the weight of the shell, which, with the pieces of the projectile, had travelled a further 300 yards. The fragments had all been picked up together. In the battery of a battleship or cruiser, the havoc wrought by that shell would have been terrible. In the "Libertad" the 7½-inch guns gave a velocity of 2,950 feet per second, and at 4,600 yards they would perforate Krupp-cemented armour 7 inches thick, while at 2,500 yards they would perforate 7½-inch plate. Those figures showed the value of thick armour when attacked by projectiles of thoroughly good quality. He could not agree to the theory that the accident to the "Maine" had been caused by the bursting of a cast-steel shell. He was not a believer in cast-steel projectiles, either shot or shell, because he did not consider they could be made to the same degree of perfection as forged projectiles. An important point in connection with the penetration of armour was, that the energy should be concentrated on the smallest possible area of the plate. By such concentration the maximum amount of damage was done, and a better chance of punching the plate, and thereby getting behind the armour and killing the crew, or damaging material, was obtained.

Major Barlow. Major H. W. W. BARLOW, R.A., thought the meeting must be somewhat bewildered. It had heard statements from Mr. Hadfield, with which he was rather inclined to agree; but those statements had been to some extent controverted by Lieutenant Dawson. He had little doubt that both those gentlemen were right within their knowledge; because in such matters, where plates differed and projectiles differed, it was almost impossible to get absolutely similar conditions. He wished, however, to draw attention to two points in connection with the question under discussion. In his official capacity he had watched with the greatest care the question

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of armour-plates. In most cases the proof projectiles had been shell, because he had not to deal much with armour-piercing shot. But in regard to armour-piercing shell he had noticed time after time the statement that when hard plates were attacked they yielded by punching. It was all very well to say that the cap protected the point, and therefore allowed it to enter the plate; but how could the protection of the point affect the question when an irregularly shaped piece of the plate, sometimes much larger in area than the cross-section of the projectile, was punched clean out? Again, in dealing with shell the bursting-charge had to be considered. He had examined the records of the performances of a vast number of proof shell, most of them without caps; but he had never known a shell, capped or uncapped, to go through a hard plate intact and unbroken; and he did not believe such a thing had ever occurred—it being understood, of course, that the plate was not absurdly overmatched by the projectile to start with. If the shell broke up at the face, even if the fragments were carried through, the explosion would infallibly take place outside the plate. What damage would that do? He must leave those questions to be solved by others. They were most difficult points to discuss; and any one who could assist in explaining how the cap acted, or exactly what was the action of an armour-piercing shot or shell on a plate, would do a great service to his country. The grave difficulty was the enormous expense of dealing with material which cost between £500 and £600 per plate—he believed that was a low estimate—and the impossibility of making such trials by driving punches through hard steel by means of a dropped weight. He had attempted to calculate some system of doing it under a steam-hammer. He had found that he would be driving the foundations of the hammer somewhere into the bowels of the earth before he got any representation of what really happened with a gun. It was easy to talk of 5,000 foot-tons energy; but he would invite the members to calculate out what class of steam-hammer foundation would stand it. Under those circumstances, it was troublesome to make any experiments of a laboratory or workshop order which would reproduce the actual effect of a gun.

Major Barlow.

Admiral A. A. C. Parr said that his excuse for participating in the discussion was that the subject was one of great importance to him—and of course to the Navy in general—not from the manufacturer's point of view, but from the point of view of those who might have to make use of projectiles in grim earnest. On consideration of the trials and experiments which had been

Admiral Parr.

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Admiral Parr. carried out in different countries, including England, it was difficult to arrive at any definite conclusions; in some instances the necessary data were wanting, and in others the data might not agree with the results of experiments carried out at home. For instance, reference had been made to the trials at Eskmeals, when a 6-inch capped armour-piercing projectile had perforated completely a 12-inch Krupp-cemented plate. Subsequently another 6-inch capped projectile, of similar character and size, had been fired against a similar 12-inch Krupp-cemented plate, and although complete perforation had not been attained, the effect had been within an appreciable distance of the previous result. In those two cases the effect could be compared: if the plates were equal, the one projectile was somewhat superior to the other projectile; or if the projectiles were equal, one plate was superior to the other plate. Table II., which was headed, "Perforation of standard face-hardened armour by capped and uncapped armour-piercing projectiles, at normal impact," did not state what standard armour was. If it were Krupp-cemented armour, as some of the figures seemed to imply, then the Table did not bear out the Author's contention that uncapped projectiles could not perforate a thickness of armour greater than the calibre of the gun. Therefore, it was difficult to draw definite conclusions from those figures. Again, what was an armour-piercing shell? Some years ago it had been in contemplation to fill the cavity of armour-piercing shot with a high explosive. Would those projectiles then have become shell? It had already been stated that a 3-per cent. bursting-charge gave an efficient armour-piercing shell. In England it was laid down that a 5-per cent. bursting-charge was required; and the results of experiments carried out with a 3-per cent. charge could not be compared with those which would result from a 5-per cent. charge. With regard to caps, the results obtained at Eskmeals were unquestionably wonderful. When similar experiments had been carried out in 1895, the capped projectile had asserted its superiority over the uncapped at normal firing, but in oblique firing that superiority had soon disappeared. Since then the hardness of the face of the plate had been much increased, the manufacture of the projectiles had been improved, and the firing-velocity had also been increased. All those factors tended towards the efficiency of the cap. But he would like to ask whether it was in contemplation to attack 12-inch or even 10-inch armour with a 6-inch projectile. If not, the question was whether capped projectiles would give the best results, if the thinner plates of the secondary armament of a battleship were

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attacked with 6-inch guns, and primary armament was left to attack the heavier armour Taking projectiles fired at casemate armour, such as was used on modern battleships, which projectile would have the greater effect—a capped projectile which passed cleanly through one side without making any fragments to speak of, and perhaps passed out at the other; or one which drove in a portion of the plate and then broke up into fragments? The possibilities of the capped projectile had been mentioned, but nothing appeared to have been said as to its limitations. He understood that there were three things necessary in order to get the maximum perforation by a projectile. First, the point should be hard enough to perforate uninjured; secondly, the head should be strong enough to follow the point without deformation; and thirdly, the walls should be tough enough not to part company from the head. With normal firing, and with armour-piercing shot, those requirements were met in a measure; and the cap would probably be equally effective at oblique firing, if the line of perforation of the projectile followed the trajectory. But such was not the case—at all events with hard-faced plates. When the point entered the face of the plate with oblique firing, it was deflected inward so that the line of perforation was inclined at an angle to the line of the trajectory. The consequence was that when the head of the projectile entered the plate it was turned through a certain angle, while the base had a tendency to pursue its original course; so that there was a great straining action on the projectile. When that action was severe enough to make the base part company from the head, a large amount of energy was lost, and the penetration was greatly reduced. Possibly if, on the projectile striking the plate, the point gave way more or less, so as to cause no deflection of the projectile, a portion of the plate might be driven in and considerable damage be effected behind. As an illustration of his meaning, he might mention that a short time ago three 12-inch armour-piercing shot, two uncapped and one capped, had been fired at a 12-inch plate with a velocity insufficient to effect perforation. The capped projectile had penetrated about 3½ inches more than the uncapped; but on examining the plate behind, the bulge caused by the uncapped projectile had been found to be considerably greater than that caused by the capped. In fact, the capped shot had produced very little effect on the back of the plate. The possibilities of the cap being effective on armour-piercing shell were certainly much less. The walls of shell were much weaker, and consequently more likely to part company from the head. Although

Admiral Parr.

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Admiral Parr. the cap would protect the point, it was a question whether the head was strong enough to follow the point without being deformed. Some years ago, pointed common shell had been introduced, partly with the idea that the point might be effective in penetrating thin armour. He had seen several experiments carried out in the investigation of that point, shell having been fired at plates which they had been able to knock to pieces. But when the portion of the plate struck by the shell and the head of the shell fired had been found, as they had been in some instances, the one had fitted exactly into the other. The plate had been cup-shaped, and the head of the shell hemispherical, without any sign whatever, either on the plate or in the head of the shell, that the projectile had ever had a point. It would obviously be useless to cap a projectile of that description. It ought not to be difficult to say what was the largest capacity that a shell should have, in order to make the cap of any use. With regard to the spontaneous cracking of armour-piercing projectiles—not so much shot as shell—and the effect which the cracking produced on the bursting-charge, there appeared to be some difference of opinion. If the cavity were filled with loose powder, as in some of the smaller shell, when the cracking took place the powder would certainly be ignited and the shell would burst. But would a bag of serge or similar material be sufficient to protect the bursting-charge from ignition at the moment of disruption? What happened at that moment? Was a spark emitted, piercing the material of the bag and igniting the charge; or was there merely an emission of heat which would ignite fine particles of dust from the bursting-charge that might have found their way through the bag, and by that means ignite the whole charge? It had been stated in the discussion that cast-steel projectiles were less liable to spontaneous cracking than forged-steel. He did not doubt that; and if it were a fact, it was certainly one point in favour of cast-steel shell, if the same results could be obtained in penetration of armour. He would be glad if the Author could state the capacity of the bursting-charge in the latest patterns of American armour-piercing shell, and the description of plates against which they were tested. In conclusion, he had endeavoured to bring forward some interesting points, on which further information would be useful, rather than to express his opinions on the various matters he had referred to.

Mr. Whinfield. Mr. J. H. R. WHINFIELD thought the Author would probably wish to qualify his conclusion that a projectile would not penetrate hard-faced armour of a thickness equal to its own calibre,

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which was apparently drawn from the results of trials cited in the Paper. According to the diagram (*Fig. 45*, p. 41), a 6-inch projectile would penetrate a 6-inch Krupp-cemented plate, provided it had sufficient velocity. In the trials from which the Author apparently drew his conclusion, the velocity was lower than that shown by the diagram to be necessary, namely, under 1,900 feet instead of 2,200 feet per second in the case of the 6-inch plate. Possibly the Author's deduction was due to ignoring the fact that when armour-plates were tested they were proved for the purpose of their reception as armour-plates; and it would be required that the plate should not be penetrated by the projectile, the velocity of the latter being so fixed as to be actually below that at which it would perforate the plate. It must be remembered that the plates were of limited size, and that four or five projectiles attacked them over a small area, the main object being to test the bulk of plates under delivery, in order to see that they were satisfactory, and that they would certainly keep out projectiles at fighting range. In action it was very improbable that four or five projectiles would be delivered over so limited an area. The plate was required to keep out those projectiles, and it succeeded in doing so; but that was no ground for arguing that a hard-faced plate would keep out a projectile of a calibre equal to its own thickness, given a sufficient velocity. Of course, when projectiles were tested, the object was to get through the plate, but the plate presented for the reception of projectile was a Krupp non-cemented plate. He believed the thickness of the plate was equal to the calibre of the projectile, and if the projectile was a good one it did get through. But how much thicker a plate would it penetrate? Was it possible by gradually increasing the thickness to arrive at a measure of the efficiency of the projectile—that was to find out the maximum thickness a first-class projectile would penetrate? With regard to the use of pyrometers, he was not familiar with the Callendar pyrometer, but vibration considerably interfered with the use of the Le Chatelier pyrometer, which he believed was a similar apparatus. How could it be avoided in works where such things as projectiles were being made?

Mr. Whinfield.

Major A. H. Wolley-Dod thought it might assist further discussion of the Paper if he described, in a few words, the trials he had seen. Probably many of those present had not seen what took place when a projectile struck a modern hard-faced plate. Speaking of uncapped projectiles at all events, it was impossible to perforate a plate by means of a boring action similar to that observed

Major Wolley-Dod.

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Major Wolley-Dod.

when wrought-iron plates were attacked. Generally a piece was driven out of the plate, forming what was called a "disk," which was approximately of the diameter of the projectile, and might be almost cylindrical in form, but more usually was expanded considerably towards the back, so that the back of the perforation was two or three times the diameter of the front. On examination of the disk, there was usually evidence of a strong tendency to punch the central portion through. There was little actual penetration of the plate by the point of the projectile, so that if the plate overmatched the projectile, it might safely be said that the depth of penetration was usually less than half the thickness of the plate; it was certainly so in the thicker plates. From a comparatively insignificant indentation in the plate to the complete punching out of a large disk was therefore but a short step. Sometimes the face of the plate was considerably dished around the point of impact; that effect was not common, but it had been noticed, and it appeared to happen when the plates were somewhat softer than usual. The depression might be 2 to 3 feet in diameter, and was usually bounded by circumferential cracks. When it was observed, the actual hole was generally rather small—sometimes even smaller than the diameter of the projectile itself—although the plate might be completely punched, and portions of the projectile might get through. Plates which showed no dishing usually produced a large disk at the back, owing, apparently, to their extra hardness. With capped projectiles the effect was found to be altogether different; then there appeared to be a true boring action, similar to that which occurred in attacking wrought-iron armour. When the plate overmatched the projectile, the hole in the plate was of considerable depth, and usually was of the form of the projectile itself, sharp-pointed. A large disk was seldom knocked out behind, and if the projectile perforated, it made a cylindrical hole just as it would do in perforating wrought-iron plate. Another point in connection with the question of perforating plates by projectiles was the variability of plates. Even with plates of the same kind, for instance, Krupp non-cemented, the results varied considerably, although the projectiles were, to the best knowledge and belief of the manufacturers, identical in quality and power. The effects of those projectiles varied even on the same plate; so that there was strong ground for the belief that the resistance of a plate differed in different parts of its surface. It was difficult, therefore, to find a means of calculating beforehand what thickness of plate a given projectile, fired at a given velocity, would perforate. Various formulas were

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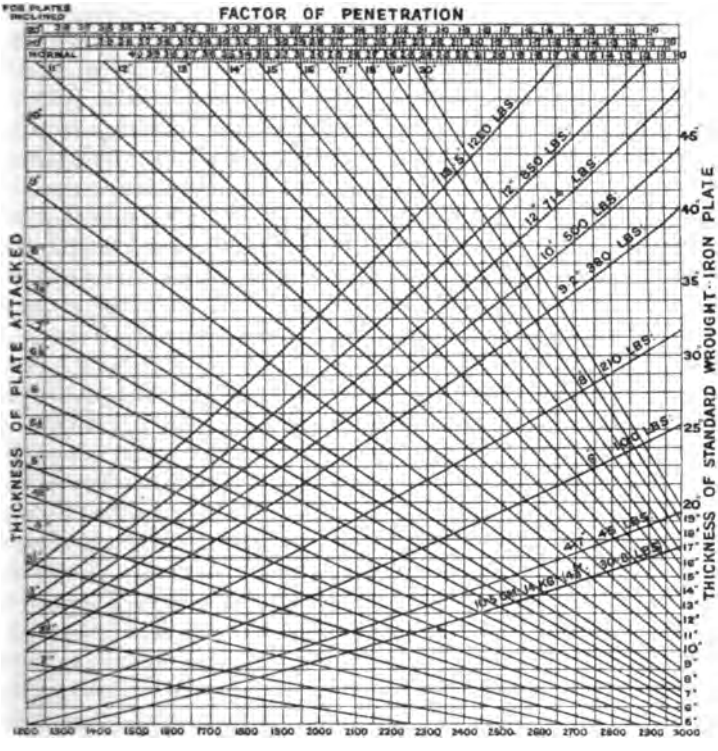
in use for the purpose. Many people preferred the Krupp formula, according to which the thickness perforated varied directly as the velocity. Another formula was Captain Tressider's, according to which the thickness perforated varied as the velocity raised to the power $\frac{3}{2}$. That formula was based upon the perforation of wrought iron, and therein he believed it had the great advantage

Major Wolley-Dod.

Fig. 45.


FACTOR OF PENETRATION
THICKNESS OF PLATE ATTACKED
THICKNESS OF STANDARD WROUGHT-IRON PLATE
STRIKING-VELOCITY : FEET PER SECOND.

of referring all plates to some common standard. Wrought iron, as used in armour-plates, was of very uniform quality, and served as a standard for comparing the results with all other kinds of plate. The formula was capable of being plotted on a diagram such as was exhibited (*Fig. 45*). On that diagram it was possible to read off in a few seconds the thickness of wrought iron perforable by a given projectile. Then by taking the ratio of the thickness of wrought iron perforable to the thickness of the hard plate attacked,

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Major Wolley-Dod. the "factor of penetration" of the projectile could be arrived at. This ratio became identical with Captain Tressider's "figure of merit" of the plate when it was just perforable. In practice it was found that the figure of merit of a Krupp non-cemented plate might vary between 2·2 and 2·9, which meant that the plate had a resisting-power 2·2 to 2·9 times that of a wrought-iron plate. The question he would like cleared up—and he hoped some of the members present would be able to throw some light on it—was, what was the actual cause of the various phenomena which he had described? The perforation of a plate by a projectile took place in an exceedingly short time. A 6-inch projectile striking a 6-inch plate with a velocity of 2,000 feet per second, which was not considered a high velocity nowadays, passed through in about $\frac{1}{2000}$ second: but there was no doubt that the question of the mastery of the plate or of the projectile was determined in much less time than that. Further figures were therefore unnecessary to indicate the enormous strain set up in the plate by an armour-piercing shell. Those shells—that was, projectiles really recognized as such, with a bursting-capacity of 5 per cent., or more—usually, if not always, broke up under the strain; and armour-piercing shot often did so, when fired normally. When fired obliquely, armour-piercing shot would almost invariably break—always when fired at an angle of 20° or more. What he would like information upon was, how was the resistance of the plate brought into play; how much of the face, for instance, took part in resisting the impact of the projectile? No doubt stresses were rapidly spread all over the plate, but could they spread in that short space of time to any distance from the area of impact? The dishing of which he had spoken might very likely happen, but the mastery of the plate must probably be determined before the dishing could take place. Another question was, at what rate was the strain transmitted along the projectile itself? Possibly the mastery of the plate was determined almost before the base of the shell had time to know what the point was doing. Those were some of the questions which the projectile-maker and the plate-maker had to deal with. No laboratory experiments could possibly throw light on them, because of the enormous stresses involved; and makers would be greatly indebted to any one who could assist in solving those problems.

Mr. Guttmann. Mr. OSCAR GUTTMANN observed that a few illustrations of the action of explosives which he wished to offer might perhaps lead to an explanation of the questions involved, to which previous speakers had alluded. In the first place, he would point out that

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a very hard material might be penetrated by one much less hard. About 4 years ago an explosion had occurred in a shell-powder manufactory, containing a wooden polishing-drum. There was a 3 feet thick traverse between one building and the other, and the wooden end of the glazing-drum had been driven against the wall, with the result that a round block of the 3-foot wall had been punched out. That would, to a certain extent, explain the action of a capped shot striking a hard-faced substance. Again, the Author stated that some thought the cap acted as a lubricator, and Mr. Hadfield had described an experiment with a hydraulic press, by which a cap had been pressed on to the projectile, showing that the cap bulged out under pressure. He had a more practical illustration to offer in an experiment made about a month ago on a small scale, but capable of being repeated on a much larger one. A method much used for testing various kinds of explosives was the test of the Austrian Military Committee, which consisted in placing on a cast-iron base a lead cylinder of exact and known dimensions. On the lead cylinder a steel plate of the same diameter was placed, and a charge of 50 grammes of the explosive was put into a tin box, which was placed on the top and exploded. About a month ago he had made similar tests with an unexpectedly violent explosive, and instead of 50 grammes he had used 100 grammes. The result had been very striking. The lead cylinder had apparently been squashed into a flat disk; but on close examination it had been found that it was not really squashed, but mushroomed out to a thin edge, and, owing to the energy of the explosion, which had probably not been more than 100 foot-tons, the lead had melted away and completely altered in structure. The steel plate on the top had been splintered into fragments, and the base of the tin box had been practically soldered to the steel plate. With regard to making experiments and finding out what really took place with armour-piercing projectiles, why not reverse the process and drive the plate against the projectile? There would be no difficulty in placing a plate on the top of a shot and exploding a charge strong enough to give 5,000 foot-tons. In that way it would probably be found that under that extreme pressure the soft cap would melt away, and so flow as to present practically no obstacle to the shot, except the retardation due to the length of the cap. Major Barlow had expressed the opinion that, even if it were capped, the shot broke up before it entered the plate. From experiments on explosives, with various metals and materials, he had reason to believe that such was not the case. When a projectile broke up on the plate there would scarcely be any pressure left behind the

Mr. Guttmann.

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Mr. Guttmann. point to drive it through. In any case, the projectile, on striking and penetrating, would acquire such a high temperature that the steel of the projectile must be completely transformed. Many were now inclined to think that steel was not a metal, but actually stood on the border-line between organic and inorganic compounds. It was really a chemical compound, and it was known that organic compounds of that kind, especially steel and other metals, were subject to what was called "sickness" at certain temperatures; that was, they suffered a complete change in their nature and structure under those circumstances. There was no doubt that the enormous amount of heat generated by the impact might so change the composition of the steel that anything might happen.

Major Minchin. Major F. F. MINCHIN, R.A., remarked that as he was usually present at trials of armour-piercing shot and shell for the Government, perhaps a few words from him might be of interest. As to the vexed question of cast-steel versus forged-steel projectiles, the Government specification left the field open to both; the Government did not care what the projectiles were made of, so long as they passed the tests. The highest class of cast steel which passed all the tests required by the specification had the additional advantage of not being so liable to spontaneous fracture as forged steel. The proofs of armour-piercing shot carried out at Shoeburyness consisted of firing the shot at a Krupp non-cemented plate one calibre thick, at normal impact. Shell were fired at steel plate of similar quality, inclined at an angle of 30°, and roughly two-thirds of a calibre in thickness. Admiral Parr had stated that oblique impact invariably broke up the projectile. In almost every case, on looking at the plate from the back, it was impossible to say in which direction the plate had been inclined. In fact, on all thin plates the action was invariably normal. He thought one of the causes of that probably was that the plates sprang tremendously, and when a plate sprang very much it was natural to expect that the action on it would be normal. But if the action on the plate was entirely normal, what became of the component of the energy in the direction tangential to the plate? That energy, he thought, was expended in breaking up the projectile. If the holes in the plates were examined closely, it would be seen, on the side to which they were inclined, that the edges of the hole were very much bruised. The reason was that the projectile struck against the edge of the hole in the plate and was broken up. Of course, when the plate was inclined at 30° to the normal, the tangential component would be equal to half the total energy of the projectile; and no armour-piercing projectile would

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stand such a blow. In future, for armour-piercing shot the Government intended to use Krupp-cemented plates, and the projectiles would be capped. That led him to refer to the trials with capped and uncapped projectiles fired at Eskmeals (p. 19). The first round fired at the 12-inch plate had had a striking-velocity of 2,799 feet per second, a penetration of 12 inches and a striking-energy of 5,705 foot-tons; the fifth round, at 2,827 feet per second, had developed a striking-energy of 5,542 foot-tons, but had penetrated only 3 inches into the plate. The work done in stopping the projectile was equal to the kinetic energy; and in the capped round, where the penetration was 12 inches, assuming the shot to have been unbroken—though in both rounds the shot actually had been broken—the average pressure throughout the plate would have been 5,705 tons. But in the other round, if the uncapped projectile, which had penetrated 3 inches, had remained unbroken, the pressure to which it would have been subjected would have been 22,168 tons. By constructing a diagram to show the variation of pressure during the passage of a projectile through a plate, taking abscissas to represent inches of thickness of plate, the pressure would be seen to rise with extreme rapidity. With soft plates, the rise was of course less rapid, but with hard-faced plates, such as Krupp-cemented, the curve of pressure rose almost vertically. Then a point was arrived at where either the plate gave way, or the shell was destroyed. If the plate gave way, the pressure either fell or remained uniform as the head of the projectile penetrated: but if the projectile was shattered, the pressure dropped almost immediately to zero. If the projectile were stopped at the back of the plate—as had happened in the trials referred to—the total area of the diagram obtained in this way was equal to the total energy of the projectile; but the point he wished particularly to call to notice was that the pressure curve rose almost vertically until something happened. He thought that meant that either the projectile or the plate was defeated in an extremely short time. For a shot which only penetrated 3 inches, the total time was $\frac{1}{5000}$ second; but he thought success or failure was determined in even a shorter time than that. Probably with hard-faced plates the success or failure of the projectile was determined in the first couple of inches of the plate. Some light might be thrown on the question why there should have been such a vast difference between those two rounds, one with a capped and the other with an uncapped projectile, by a fact in the history of armour-plates which he might mention. In 1879 Major English had tried the experiment of putting a 2-inch wrought-iron

Major Minchin.

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Major Minchin. plate in front of one of the best plates made at that time, a compound plate with a hard face and a wrought-iron back. On firing at that plate, the projectiles had passed right through it; in fact, their effect had been increased enormously by putting a soft plate in front of the hard one. At that time, as no effective means of fixing the cap on to the projectile had been known, trials of caps had proved abortive. As to the effect of the cap, one suggestion was that the cap helped to lubricate the projectile in the hole. He did not think that would hold when the pressures of the round mentioned were compared, namely, 5,700 tons against 22,000 tons. The difference could not be due to lubrication. Again, whatever the effect might be due to, it had been initiated by placing a wrought-iron plate in front of a hard plate, and therefore it could not be due to the energy of the cap. The probable cause of the greater effect obtained with a cap was either that it weakened the plate in some way—and he did not quite see how that could be possible—or else it strengthened the projectile. If it strengthened the projectile, it must do so by applying pressure to the point. There was a well-known experiment of trying to drive a needle through a halfpenny with a hammer. As a rule the needle broke; but if it was first inserted in a cork, and the cork was struck, the needle would go through. He thought the cap of the projectile had some such effect as that. It seemed difficult, however, to settle the question, without knowing the law which governed the rate at which deformation took place in a plastic substance under varying pressure. If any attempt to make a plastic substance flow very quickly increased the pressure enormously—in other words, if it required immense pressure to cause a plastic substance to flow rapidly—he thought it possible an explanation of the marked effect of the cap might be found. The Krupp formula referred to by Major Wolley-Dod had often been misapplied. It merely stated that the thickness of hard-faced plate which could be punched by a projectile of a certain calibre varied with the velocity employed. It did not say—and that was where the formula was misapplied—that if a projectile was fired at any plate, the penetration varied with the velocity. The plate and the projectile must be matched. Messrs. Vickers had driven a 6-inch capped projectile through a 12-inch plate with a striking-velocity of 2,800 feet per second. Other trials of Krupp-cemented plates had shown that a 6-inch capped projectile could be just depended upon to get through a 6-inch Krupp-cemented plate with a striking-velocity of 1,950 feet per second. The square of 2,800 was about double the square of 1,950, and it therefore looked as if,

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with normal firing of capped projectiles against Krupp-cemented plates, the thickness of plate which could be perforated varied as the square of the velocity. Further experiments were required, however, before that could be sustained. He agreed with Admiral Parr in regard to the practical value of caps being greatly discounted. The value of the cap increased enormously with the velocity, and at fighting ranges the velocities were somewhat low: further, when the angle of impact exceeded about 15°, the value of the cap was diminished because the projectile was invariably broken up. Therefore he thought that although the cap had probably come to stay for armour-piercing shot, yet for armour-piercing shell, the function of which was to attack unarmoured portions of ships, he thought the cap would probably not be found worth employing, unless it were reserved for some special purpose. Major Minchin.

Mr. A. G. M. JACK wished to refer briefly to the comparative value of cast and forged armour-piercing projectiles. Mr. Hadfield had upheld the advantage of the cast armour-piercing shot, and not of the forged. From 1887 to 1897 Messrs. Hadfield had manufactured forged projectiles only, and it might be asked why a change had been made. The reason was that Mr. Hadfield's researches into the properties of steel, with some of which most of those present were probably acquainted, had shown that under certain conditions cast steel gave better results than forged. Not only had better results been obtained under firing-tests, but, above all, there was greater freedom from liability to premature fracture. There was no monetary factor in the matter, for the older forged projectiles had been more profitable to the manufacturer than were the cast. Forged projectiles were relatively simple to make; special heat treatment was not necessary. On the other hand, the processes to which the cast projectiles were subjected were the result of many years of careful investigation. With regard to the action of the cap, his own opinion was that the explanation was comparatively simple. In the process of punching or piercing metal plates at an angle, or of abnormal thickness, under which conditions the punch would quickly be destroyed, it was found that if the punch were enclosed in a cylindrical casing, which by means of separate motion held the work down during perforation, operations which were otherwise difficult, or in fact impossible, were rendered relatively easy. He believed the same sort of action took place on the point of the projectile, which at the crucial instant was protected from disintegration by the surrounding cap of mild steel. Mr. Jack.

Mr. WM. LEIGHTON JORDAN observed that, throughout the Paper Mr. Jordan.

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Mr. Jordan. and the discussion, it had not been clearly recognized that the manner in which the cap must act was by weakening the resistance of the plate. It was convenient to speak of it as an increased power of penetration, but the real effect was a diminution in the ratio which the power of resistance bore to the power of penetration. There was no real increase of force, and he attributed the greater power of penetration to the fact that when the cap struck the plate it set up a condition of vibration before the hard point of the projectile reached the plate. Many years ago, when dealing with the action of vibration in quite a different subject, the idea had occurred to him that the theory might be utilized for the purpose of facilitating the penetration of armour-plates, by arranging a double shell, and allowing a telescopic action between the interior and the exterior portions, so as to cause two separate blows in rapid succession, giving the second blow the advantage of the vibration set up by the first. However, he had almost immediately given up the thought of trying to obtain any practical result from the idea, because it had appeared to him then, and indeed until the reading of the Paper, that it was quite impracticable to enable the point of the shell to strike the second blow without losing at least half of its momentum before that second blow could be struck; and by so doing the second blow would have less than a quarter of the force given to the shell. Therefore, the idea had seemed to him to be quite useless. The invention of the cap, however, appeared to surmount that difficulty. The caps which had been described were not constructed to meet the object he had in view, but all that was necessary was to allow a small space between the cap and the point of the shell; because with the cap arranged as at present there was a continuity of pressure from the moment the cap touched the armour-plate until the hard point of the shell struck it. By leaving a small space between the cap and the hard point of the projectile, so as to make a separation between the two blows given respectively by the cap and the hard point of the shell, vibration would be set up which would facilitate the penetration of the plate. It was impossible to enter into a theoretical explanation of the mechanism of the vibration in such a case, but he might in a few words show what was the point he had in mind. In experiments with pendulums it had been shown that any disturbing action had its greatest effect at the extremity of each swing. Also, it appeared evident that, as the pendulum vibrated, the disturbing forces acted upon it more easily than when it was at rest. Forces which would not then act would do so when it was vibrating.

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The reasoning he went upon was, that it was impossible to draw any hard-and-fast line between the force of cohesion in a plate and the force of gravitation which connected the ball of the pendulum with the earth. In theory there was precisely the same action. A shot striking a steel plate while the latter was in a condition of vibration would drive the particles of the plate before it, because they would not then be cohering with the particles around them with the same strength as when the plate was at rest, and therefore the second blow, coming upon the plate while it was in a condition of vibration, carried along with the momentum of the projectile the particles which it struck. Mr. Jordan.

Mr. WILLIAM CARNEGIE offered yet another explanation of the superiority of the capped compared with the uncapped projectile. He thought every engineer would admit that, with two projectiles of equal weight and equal striking-velocity, and therefore possessing equal momentum, but one capped and the other uncapped, a given quantity of momentum would be destroyed more quickly in the uncapped projectile than in the capped. The cap lengthened the time during which the momentum was destroyed. If that were granted, the quotient of the momentum destroyed divided by the time during which it was destroyed, gave the time-average force of the blow on the plate, and the reaction of the plate on the projectile. If that time was less in the case of the uncapped projectile, the force was greater; and he submitted that the force was so great with the uncapped projectile that it smashed the projectile before it had time to utilize its energy in perforating the plate. As an illustration of the time-effect, water might be imagined to be flowing at a given velocity through a pipe in which was a cock. If the cock were shut in $\frac{1}{100}$ second, a definite force was induced in the cross-sectional area of the pipe. The force in pounds would be the weight of the water behind the cock multiplied by the velocity in feet per second and divided by 32·2, divided by the time in seconds taken to destroy that momentum. If the cock were shut in 1 second, then the force induced in the pipe would only be one-hundredth of that in the first case. In his opinion, that was the action of the uncapped and the capped projectiles respectively. There were no means of ascertaining the exact time during which a definite quantity of momentum was destroyed, though it had been suggested it was about $\frac{1}{2000}$ second. He wished to know if any experiments had been made which tended to prove that such was the time taken to perforate the plate. It was not necessary, however, to have an absolute value for the time, if the comparison were only of Mr. Carnegie.

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Mr Carnegie. capped versus uncapped projectiles. If it were admitted that the same quantity of momentum was destroyed in a longer time in the case of the capped projectile than in that of the uncapped, then the force with which the plate reacted on the capped projectile was less in the case of the capped than in that of the uncapped. He did not think that Major Minchin's way of looking at the matter, namely, calculating the force on the plate, was the right one. Major Minchin had divided the kinetic energy by the distance passed through in feet. In the first case, that of the 12-inch perforation, the kinetic energy divided by unity gave the force in tons. Then Major Minchin had taken another case where the penetration was 3 inches, and had found that the force was much greater, namely, 25,000 tons. But in that reasoning it was assumed that the velocity of the projectile was reduced uniformly. Who could say that such was the case? If there were no penetration, the kinetic energy divided by the distance passed through, which was zero, was infinite—which he thought would be admitted to be absurd. In case any member felt doubt in regard to the time-effect, he might mention a simple experiment he had made in order to clear up the matter in his own mind. Two iron balls, one of them having a small piece of india-rubber on the face of it, had been raised to the same height above a plate. They had been released at the same instant, and had therefore struck the plate with the same velocity. The one having no india-rubber on the face had rebounded more quickly. That indicated that its momentum had been destroyed in a shorter period of time, and therefore the time-average force reacting on the cast-iron ball without the rubber had been greater than in the case of the one faced with rubber. He submitted that therein lay a possible explanation of the superiority of the capped over the uncapped projectile.

Mr. Harding. Mr. W. J. HARDING submitted, as a contribution to the conjecture that the cap was a lubricator, a few somewhat homely examples from every-day practice which might tend towards an explanation. The blacksmith lubricated his punch with water or coal when he was punching iron. As the hole became deeper, he puts little peas of coal into the hole, which serve for lubrication, and prevented the two surfaces of metal from coming together and seizing. That principle was made use of in making tubes, where the tube was a blind end, a mixture often used for the purpose being one composed of damp saw-dust and coal. The gas liberated from the coal acted as a lubricator, enabling the metal to flow over the ram and not seize it. In tube-drawing,

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it was usual to allow the tubes to remain longer in the sulphate of copper bath than usual, and the coating of copper which resulted enabled two or three cold draws of the tube to be made, and the metal did not suffer, or become brittle or hard. The same effect was produced by tinning the outside of the tube for cold-drawing, which enabled the draw to be made without distressing the steel itself, and obviated annealing for two or even three draws. He had seen the effect of projectiles about 20 years ago on board the "Huascar," taken from the Peruvians. Twice the turrets had been cleared by the Palliser projectile, and their appearance had given the idea that the splitting up of the projectiles into cubes of metal was what was desired in war-service. *Fig. 8* in the Paper looked like an old friend. In his boyhood he had learned a little trick from a blacksmith. The smith would ask a boy to strike a hammer on the anvil so that it would not rebound. The boy would at once say it was impossible. Then the blacksmith, by putting another hammer over the first and striking both on the anvil, would obtain a dead-beat blow. He had thought that a projectile like *Fig. 8* might be made, and had written to Lord Armstrong, pointing out that principle. Lord Armstrong had courteously intimated that he did not think much of the idea. Possibly the cap itself produced the effect of the double hammers, and also acted as a lubricator, as suggested. Mr. Harding.

The AUTHOR, in reply, observed that Colonel Bainbridge had referred to the means of attachment of the cap to the projectile as a possible source of weakness. It had been found, however, that when a capped projectile passed through a plate, it very often fractured, not through the groove or the notches whereby the cap was attached, but elsewhere; showing that the apparent source of weakness did not exist. He had been pleased to hear from Lieutenant Dawson that he had experimented, and had found capped projectiles fired at oblique impact so satisfactory in their results. It was to be hoped that the results of more public trials would also be as satisfactory. All the private trials referred to by Lieutenant Dawson had been carried out with capped shot, with the exception of one capped 7·5-inch shell having a bursting-charge of 6 lbs. 12 ounces, or 3·3 per cent., which was lower than was laid down in England, where 5 per cent. was considered to be the bursting-charge for a shell, as had been pointed out by Admiral Parr. A Harvey-Krupp steel plate had been perforated at Shoeburyness about 4 years ago by a Hadfield cast-steel capped shot of 4·7 inches calibre, at an angle of 20° to the line of fire. This 6-inch plate had previously been attacked obliquely by several 6-inch forged- The Author.

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The Author. steel uncapped shot, and no shot of this calibre had perforated it. These remarkable results obtained 4 years ago were additional evidence of the value of the capped projectile at oblique impact. With reference to the question of cast steel versus forged steel as a material for armour-piercing projectiles, much difference of opinion seemed to exist. It was important, however, to note that Major Minchin had found from his experience that the highest class of cast steel which passed all the tests required by the specification had the additional advantage of not being so liable to spontaneous fracture. The processes to which cast-steel projectiles were subjected, and the many years of investigation had rendered this result possible. Mr. Hadfield, referring to the Author's experiments with compression tests mentioned on page 13, had suggested that a table might be given, showing the results obtained. The observations in question had been taken from the walls of a 6-inch armour piercing cast-steel shell, quenched at temperatures ranging from 600° C. to 1,000° C., by increments of 50°. It had been found that a pressure of 200 tons per square inch gave a compression of a few thousandths of an inch only to all test-pieces, except those dipped at 600°. The temperatures shown in the cooling-curve (*Fig. 32*) had been taken from the interior of a projectile drilled to within 1 inch of the point, so that they represented practically the temperature of the outer surface. Admiral Parr thought Table II. seemed to contradict the conclusion (p. 16) that uncapped projectiles could not perforate a thickness of armour greater than the calibre of the gun. While the Table showed that uncapped projectiles of more than 6 inches calibre, having striking velocities above 2,000 feet per second, did perforate plates of a thickness at least equal to the calibre of the projectile, it also showed that projectiles under 6 inches did not. Again, in Table VI. it would be observed that even capped shells up to 8·26 inches calibre, did not perforate face-hardened armour-plate (according to the Krupp standard) whose thickness was equal to the calibre of the gun. From these facts, from the results obtained with face-hardened plates made by Messrs. Schneider and Co., and from the recent English trials referred to on p. 17, he felt justified in the conclusion at which he had arrived. There were differences of opinion as to the cause of spontaneous cracking and its effect upon the bursting-charge. Cracking usually took place in the head of the projectile, and sometimes a small portion of the cavity was exposed. Loose powder in the cavity would certainly be more dangerous than if it were in a bag made of serge or similar

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material. He had heard unfilled shell crack with a loud report, but had neither observed nor heard of any spark being emitted, or any sensible rise in the temperature of the shell taking place at the moment of rupture. Ignition of the charge in a filled shell at such a moment would appear to be the result of irregular fracture causing a portion of the head to fall off, tearing the bag and igniting the charge by friction; or if the broken part was thrown from the shell violently, it might rebound and strike the charge, causing ignition. He agreed with Mr. Whinfield that it was difficult to use the pyrometer in workshops where there was much vibration, but it was quite possible to make the foundation on which the instrument rested sufficiently free from vibration for all practical determinations. Several theories had been advanced in order to explain the reason why the cap aided the projectile in piercing armour. The time-element referred to by Lieutenant Dawson and other speakers, was no doubt one of the principal factors in the solution of the problem. It would be difficult to state precisely how much more time was taken by a capped than by an uncapped projectile in penetrating armour. It was obvious, however, that, since the time was longer in the case of the capped projectile, the momentum was not destroyed so quickly, and therefore the time-average force was less. A very small portion of this force was spent in destroying the cap, as the ratio of the hardness of the material of which it was made to that of the head of the projectile was about 1 : 10. The effect of this smaller time-average force upon the capped projectile must be to lessen the severity of the blow, and tend to keep the projectile whole. Again, since less time was taken in destroying the momentum of the uncapped projectile, the rate at which its kinetic energy was destroyed was higher, and therefore the rate of generation of heat was higher. Before the point of the uncapped projectile had penetrated a few inches, the heat generated was sufficient to extract from it the very property of hardness upon which successful penetration largely depended, thereby preventing the projectile from completing its work. This fact had been clearly demonstrated in the Eskmeals trial, referred to on p. 19, wherein the heat generated had been sufficient to fuse the point of an uncapped projectile in the plate after penetrating 3 inches. Mr. Jordan favoured the theory that the plate was weakened by the cap, as the effect of the latter was to set up vibrations in the plate, which weakened the cohesion of the particles, and made the work of the projectile easier. The Author agreed with Mr. Jordan, and thought that the cap had the double

The Author.

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The Author. effect of lessening the sudden shock upon the projectile, and weakening the plate at the same time. The effect when armour-plate was struck by an uncapped projectile might in some degree be illustrated by the curious result which was obtained when a slab of flint or glass was struck by a hammer with a rounded face; a cone of glass or flint, having its apex at the point of impact, was separated from the rest. Majors Barlow and Wolley-Dod had spoken of the punching action of projectiles, and of irregularly-shaped pieces of plate being punched clean out. With the cap, however, there appeared to be, as Major Wolley-Dod had said, a true boring action similar to that which occurred in attacking wrought-iron armour; and this was no doubt due to the weakening of the plate by the first blow received from the cap. Mr. Oscar Guttmann's experiments were interesting and suggestive, and should lead to further investigation of the imperfectly understood action of the cap upon the projectile, and upon the plate.

Correspondence.

Prof. Arnold. Professor J. O. ARNOLD congratulated the Author on his valuable, interesting and suggestive Paper, which filled a gap in the literature of steel metallurgy. The statement in the Paper that the changes produced by the operations of hardening and tempering were mysterious, was very true, with reference to the exact molecular constitution of the steel at any given stage. This, however, was a matter of academic rather than of practical importance; practically the fundamental laws governing the operations of hardening, tempering and letting down, were fairly well known. To take the simplest example, iron containing 0·9 per cent. of carbon consisted entirely of the compound constituent, pearlite ($21Fe+Fe_3C$). This formula had passed out of the region of speculation and had been repeatedly proved, analytically. Such a steel really consisted of an intimate mechanical mixture of about 87 per cent. of iron with 13 per cent. of the normal carbide of iron. On heating this mixture to 700° C., a molecular convulsion took place, accompanied by a considerable absorption of heat. After this molecular change, the carbon which before had been chemically associated with only 12 per cent. of the mass of iron, became molecularly associated with the whole mass. On rapid

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quenching, the carbon was trapped in its new condition, causing the steel to assume the hardness of quartz. Then, on heating to about 200° C., the attenuated carbide alloy began to decompose, and at 400° C. it again passed into the relatively soft mechanical mixture already formulated. But, by arresting the tempering operation at any point by re-quenching, any desired degree of hardness might be retained. The carbon change-point, however, was greatly influenced by the presence of various elements such as tungsten, chromium, nickel, vanadium, etc. As an example, the case of tungsten might be selected. If a 0·9-per cent. carbon steel with 3 per cent. of tungsten was cooled from, say, 900° C., the change-point of the carbon was lowered nearly 100° C.; that was, the recalescence which would take place in the plain carbon steel at about 680° C. did not occur till about 590° C. in the carbon-tungsten steel. Hence, such steel could be sufficiently hardened at a much lower temperature than ordinary steel. Nevertheless, an enormous amount of work remained to be done in obtaining pyrometric records of the recalescence phenomena of the numerous combinations of the triple alloys of carbon, nickel and chromium which were in practical use at the present time. Prof. Arnold.

Lieutenant-Colonel L. CUBILLO remarked that the Trubia arsenal had devoted special attention to the manufacture of armour-piercing projectiles. Since 1875, when this manufacture had been begun with the Palliser projectile, the subject had not been overlooked for a moment. The Palliser projectile, made of cast iron, had been cast in an iron mould, so that the point cooled in contact with a cast-iron chill. Fired against wrought-iron armour it had proved to be excellent; against mild-steel plates the results obtained had been mediocre. The chief difficulty in manufacturing Palliser projectiles had been to obtain a suitable mixture of cast iron giving to the projectile the proper gradual hardening from the point to the shoulder. At first, when in the manufacture of projectiles the work of the metallurgist had not been assisted by the metallurgical laboratory as effectively as it was now, it had been necessary to rely upon experience in determining the best mixture. Later on, the influence of silicon on the behaviour of carbon having become known, the formula for obtaining an iron containing the silicon and manganese requisite to produce good hardening had at once been fixed. At present, the process possessed only historical and retrospective interest; steel had supplanted cast iron in the manu- Col. Cubillo.

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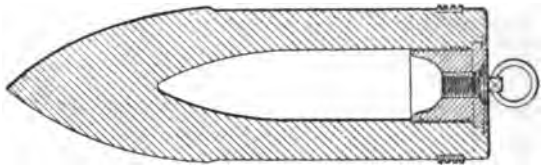
Col. Cubillo.

facture of armour-piercing projectiles. In Trubia two kinds of steel projectiles had been made. One (*Fig. 46*) was the chrome-steel projectile manufactured between the years 1885 and 1899 with the following average percentages of iron and chromium :—Carbon 0·8 per cent.; chromium 1·00 per cent. The weight of the steel castings had been such as to allow two projectiles to be formed of a calibre of 24 centimetres to 30 centimetres. They had been forged in the manner described by the Author, and after annealing the operations of turning, boring, etc., had been carried out. The most difficult operation had been the hardening; it had been performed by heating the projectiles in an upright gas-furnace at a temperature between 780° C. and 800° C.; then transferring them to an iron tank, wherein a jet of oil at a pressure of half an atmosphere acted upon the point of the projectile until the tank was full, the capacity of the tank being sufficient for holding a volume of oil, the weight of which was ten times the weight of projectile. The tests made on projectiles manufactured by this process had given excellent results.

Fig. 46.



CHROME-STEEL ARMOUR-PIERCING PROJECTILE FOR 24 CENTIMETRE GUN.

A few ruptures, however, had been noticed, which occurred with every method of hardening. In nearly every case the rupture of the projectile had taken place midway between point and shoulder, across a plane normal to the longest axis of projectile. As a rule these fractures had happened at times of sudden change of temperature. The armour-piercing projectiles at present manufactured for quick-firing guns (*Fig. 47*) were of nickel-chrome alloys. As in every kind of nickel steel, the quantity of carbon was not high; the average composition of these projectiles was carbon 0·55 per cent.; chromium 0·65 per cent.; nickel 2·60 per cent. The projectile was provided with a cap of steel, having the same composition as the projectile. Forged with the care required by nickel steel, they were then annealed, and after the machine-shop operations they were hardened twice. The first time the projectile was heated to 740° C., and wholly immersed in a bath of oil, the temperature of which was 24° C.; the second time only the point

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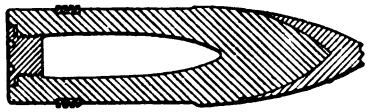
was hardened, in water which flowed in a jet on to the inside and the outside. The temperature for this second tempering was 780° C. for the projectile, and 22° C. for the water. The caps were hardened in water, the top part only being heated to a bright red heat; then they were immersed in water. The precaution recommended by the Author in regard to heating and cooling the projectile —especially its point—were useful and worthy of consideration by all concerned with the manufacture of armour-piercing projectiles. Col. Cubillo.

Fig. 47.



NICKEL-CHROME-STEEL ARMOUR-PIERCING PROJECTILE FOR 15-CENTIMETRE QUICK-FIRING GUN.

Messrs. SCHNEIDER & Co., of Le Creusot, pointed out that the numerical coefficients given by Mr. Delmas related to the formula of the Gâvre Commission, not to the formula of Colonel Jacob de Marre. Consequently, those coefficients were not comparable with K_2 in Table I. of the Paper. Further, they related to trials of plates chosen at random from completed lots, and represented the results of firing under average conditions: the results obtained with such plates could not be compared with those obtained from plates specially made for trial. Messrs. Schneider.

The AUTHOR, in reply, remarked that Professor Arnold's lucid remarks on the changes which took place in steel during the processes of hardening and tempering were of practical importance. It was interesting to find that Colonel Cubillo's methods of manufacture agreed closely with those described in the Paper. If, as Messrs. Schneider & Co. stated, the numerical coefficients given by Mr. Delmas related to the formula of the Gâvre Commission, and not to the formula of Colonel Jacob de Marre, then they were comparable with K, instead of K_2, in Table I. The Author.

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17 February, 1903.

JOHN CLARKE HAWKSHAW, M.A., President, in the Chair.

The PRESIDENT said he regretted to have to announce the death of Field-Marshal Sir Lintorn Simmons, Honorary Member. There was no need to recall to the members his distinguished career as a soldier in the Crimea and elsewhere, and in the many responsible positions which he had afterwards filled so ably. By his connection with the Railway Department of the Board of Trade in early

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life he had been brought into contact with many of the older engineers, and many of them had enjoyed his friendship throughout life. At their meeting that evening the Council of the Institution had passed the following resolution:—"That the Council deeply regret the death of Field-Marshal Sir John Lintorn Arabin Simmons, R.E., G.C.B., Honorary Member, and desire to convey to his family an expression of sympathy in their bereavement."

The discussion on the Paper on "The Manufacture and Efficiency of Armour-Piercing Projectiles," by Mr. David Carnegie, occupied the evening.

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24 February, 1903.

JOHN CLARKE HAWKSHAW, M.A., President,
in the Chair.

(Paper No. 3397.)

"Mechanical Handling of Material."

By GEORGE FREDERICK ZIMMER, Assoc. M. Inst. C.E.

THE application of mechanism to both the handling and the conveyance of material has of late years assumed a paramount interest, owing to the economy which is effected thereby. Increased competition, met with in all branches of manufacture, has enhanced the necessity of economy in every department. The importance attached to hand-labour has become less and less; and labour-saving appliances are everywhere regarded as being as essential to the progress of manufacturing industry as is lubrication to the reduction of friction. So keen is modern commercial competition, that the margin between the cost of the raw material and the price of the finished product has dwindled to the smallest amount; consequently, the manufacturer is continually appealing to the engineer to effect further economies in working, and so reduce the cost of production to a minimum. In round figures it may be taken that the saving of one man's wages warrants the investment of £1,000 in machinery; hence, in the quest for economy, the engineer is ever on the alert to reduce the wages-bill and produce everything automatically. The modern flour-mill may be cited as an example. So perfect is its automatic working, that wheat may be unloaded from an ocean-going steamer, stored, cleaned, graded, ground, dressed, packed, weighed, registered, and delivered into a railway truck for despatch to a customer, without any manual labour whatever. The consequence is that, whereas a few years ago it would have required twenty or thirty men to produce a given quantity of flour, it now requires only three or four, simply for general supervision, lubricating, cleaning, etc. Nor

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should it be hastily assumed that the multiplication of mechanical appliances is detrimental to the interests of the worker. On the contrary, his daily life is thereby made easier, his intelligence is improved, and his wage-earning capacity is increased.

The main questions which every producer of raw material and every manufacturer has to consider in relation to this subject may be summarized as follows:—

(*a*) Can the working-expenses be reduced?

(*b*) Can such reduction be attained without sacrifice of efficiency?

(*c*) Is the saving commensurate with the outlay involved?

(*d*) Can the maintenance of the necessary appliances be met by the amount saved in labour, leaving a margin for interest on capital invested, depreciation and other contingencies?

(*e*) Will the work be as well done?

As regards the conveyance of materials from one point to another, all these questions can be answered affirmatively; and no one can afford nowadays to ignore their consideration. A man employed with a shovel, barrow, or hand-truck, must be regarded as a wasteful expense, to be tolerated only in cases of extreme necessity.

There is probably no field wherein labour-saving machinery has so large a scope as the mechanical handling of raw materials; and yet the appliances employed are comparatively few and to some extent obsolete. It may therefore be of interest to give a short description of the older apparatus employed for this purpose, before dealing more fully with that which has been introduced recently. The subject, as a whole, is very extensive, and this Paper will be limited to the consideration of methods which deal with the material continuously, that is, which receive and deliver it in an uninterrupted stream—such methods, for example, as are employed in factory-yards, coal- and other mines, gas- and electric works, etc.: while appliances which handle the material intermittently and over long distances, as would be done by light railways and ropeways, will be passed over. The handling of raw materials continuously is best considered under three heads:—

I. Appliances for lifting in a vertical direction, or from one level to another, commonly called elevators.

II. Appliances for moving material in a horizontal direction, commonly called conveyors.

III. Appliances which combine the operations of elevating the material and conveying it simultaneously.

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I. Elevators.

Elevators in a primitive form have long been known and used, and since their introduction they have undergone but little alteration, except in details. They are generally understood to be endless belts or chains, to which are attached suitably-shaped receptacles or buckets. The chains or belts run over two terminal pulleys, which are fixed at different levels. The distance from centre to centre of these pulleys is called the length of the elevator.

Elevators are designed to suit special purposes. For instance, grain-elevators are always encased in wooden or iron trunks, of which the head and bottom are also of wood or iron. The position of the trunk for a grain-elevator is almost invariably vertical. The support for the buckets is either leather belting, cotton belting, hemp webbing, or india-rubber with insertion. For minerals, coal, coke, cement-clinker and other heavy materials, the elevators are fitted with chains and sprocket-wheels, which support the buckets. Such elevators are generally in a slanting position, with a slope to suit the circumstances. The buckets are attached to the links of the chain; and an intermediate short iron skidder-bar is inserted, which slides on well-oiled angle-bar rails on either side, and so prevents the buckets and chain from sagging. Both grain- and ore-elevators are generally furnished at the bottom terminal with tightening-gear to keep the belt or chain tight.

For elevators of large capacity, two or more strands of chain are sometimes used to support the buckets; but a drawback to the employment of multiple strands, when using ordinary malleable-iron chains, is that the different strands will stretch unevenly and throw the buckets out of parallel with each other. It is therefore always best, where possible, to use one chain of sufficient strength; or else chains with double links, that is, two links cast together, with a web in the middle. These remarks refer to ordinary malleable-iron chains only; and not to malleable-iron or wrought-iron link-chains, which are jointed together by turned bolts through bored holes. The latter kind of chain is always used for elevators of large capacity, and for heavy materials such as coal, and runs over polygon or sprocket wheels.

Position of Elevators and Speed of Running.—The reason why an elevator should sometimes be vertical and sometimes inclined is that an elevator for materials of low specific gravity can be driven at a much higher speed than one which is used for substances of higher specific gravity; because a velocity of delivery

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which would not injure grain would break up coal and other heavier and friable materials: moreover, the receiving spouts and shoots would quickly be destroyed by the impact of the material. Elevators in a vertical position are therefore suitable only for specifically light materials, and they can run at a circumferential velocity of 250 feet to 350 feet per minute. Elevators for heavy materials must be inclined so as to give clean delivery without scattering at the much lower speed of 50 feet to 160 feet per minute. For this reason elevators for specifically heavy materials require so much larger buckets, chains, etc., than grain-elevators of the same capacity.

A second reason why it is essential that an elevator for heavy materials should run up an incline lies in the fact that it is more easily driven; for part of the load is then borne by the inclined supports, instead of the whole weight hanging from the driving-gear, as it does in the vertical elevator. The angle at which to fix an elevator, in order to get the most favourable results without occupying too much space, is 45° to 60° from the horizontal.

The speed of vertical elevators for dealing with grain, etc., depends upon the diameter of the elevator-pulley, *i.e.*, the top pulley over which the band carries the buckets; because such an elevator, in order to deliver perfectly, must throw the grain horizontally a distance equal to about 1 foot more than the radius of the pulley, so as to clear the preceding buckets and reach the discharge-spout. The elevator-buckets begin to discharge when in their highest position on the top of the pulley. In order to effect perfect discharge, the centrifugal force must be sufficient to overcome the gravity of the material: so that for a specifically heavy material it is necessary to have a greater centrifugal force, *i.e.*, a higher speed of elevator, than for a specifically lighter material. In pulleys revolving at the same speed, the centrifugal force varies directly as the diameter of the pulley; for example, in a 4-foot pulley it will be twice what it is in a pulley 2 feet in diameter running at the same speed. When the speed of an elevator-pulley varies, the centrifugal force varies as the square of the speed; consequently, the centrifugal force with a pulley 2 feet in diameter running at 50 revolutions per minute will be four times the centrifugal force with the same pulley running at only 25 revolutions per minute. This indicates clearly that it is quite inaccurate to estimate the number of revolutions of the elevator-pulley by a fixed belt-speed for pulleys of all sizes, which is a mode of calculation frequently adopted.

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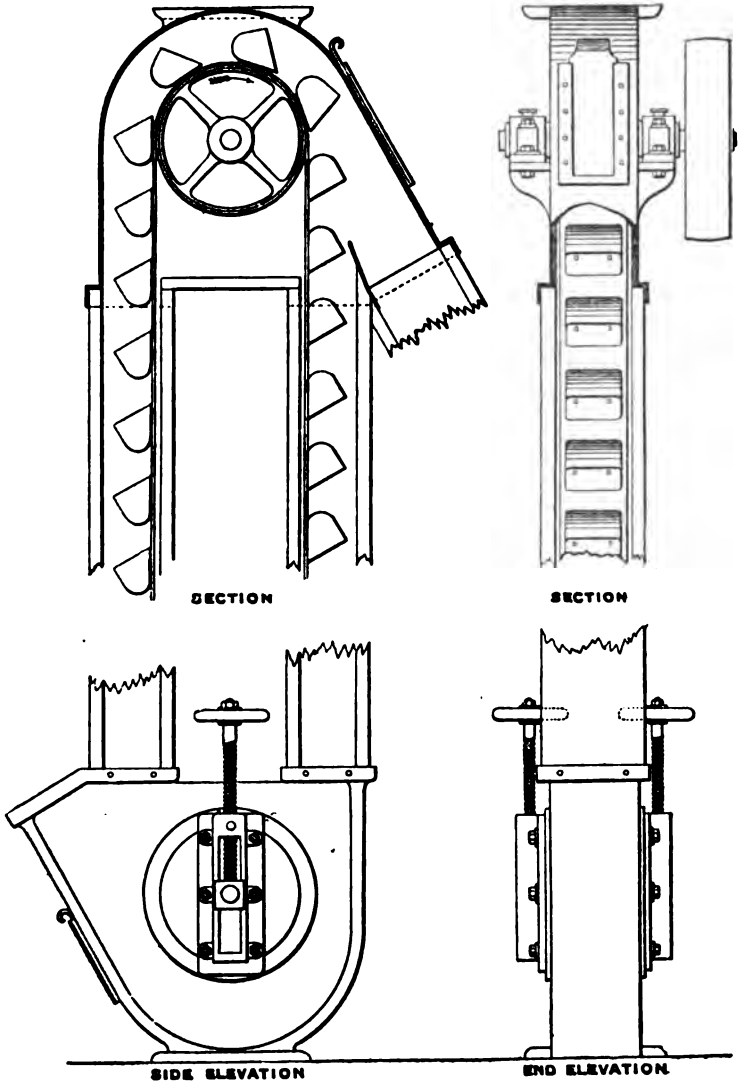
Figs. 1 illustrate the usual form of grain-elevator; and the

Figs. 1.



GRAIN-ELEVATOR.

average speed and capacity of such elevators of various sizes are given in the following Table:—

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SPEED AND CAPACITY OF GRAIN-ELEVATORS.

Diameter of Pulley.	Width of Pulley.	Width of Buckets.	Revolutions per Minute.	Capacity per Hour.
Inches.	Inches.	Inches.		Tons. Bushels.
18	11	9	60 to 65	15 = 560
21	13	11	55 „ 60	30 = 1,120
24	15	13	50 „ 55	45 = 1,680
27	17	15	45 „ 50	60 = 2,240
30	19	17	40 „ 45	75 = 2,800
33	21	19	35 „ 40	90 = 3,360
36	23	21	30 „ 35	105 = 3,920
39	25	23	25 „ 30	120 = 4,480

It is difficult to tabulate similar information for mineral-elevators, because their speed, and consequently their capacity, vary so greatly with the nature of the material to be elevated, whether hard, tough, or friable. While it is usual to run coal-elevators at 90 feet to 130 feet per minute, according to the friability of the coal, coke-elevators run at only 50 feet to 90 feet per minute. On the other hand, minerals which do not deteriorate through breakage can be elevated at the rate of 120 feet to 160 feet per minute. The capacity of such elevators depends on the speed and on the size and pitch of the buckets. In the following Table are given a few particulars of the speed and capacity of coal-elevators :—

SPEED AND CAPACITY OF COAL-ELEVATORS.

Width of Buckets.	Pitch.	Speed of Travel.	Delivery.
Inches.	Inches.	Feet per Minute.	Tons per Hour.
12	18	120	20
18	18	120	30
24	18	120	40

Figs. 2 and 3 show the most common form of mineral-elevator, *Fig.* 2 representing the top and *Fig.* 3 the bottom part of the same elevator; while *Fig.* 4 shows a form often adopted when the nature of the material prevents it from being discharged readily out of the buckets, or where local conditions, such as want of space, etc., render it necessary to fix the elevator at a

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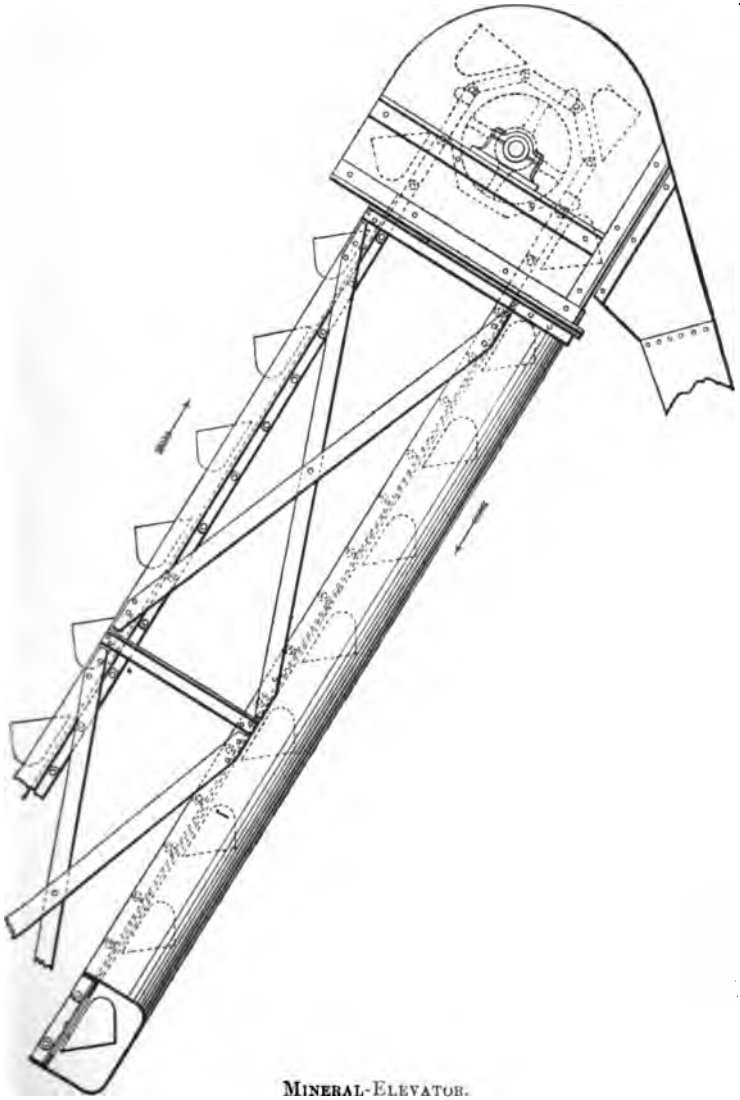
steeper slope than 60°. It is apparent that an elevator like

Fig. 2.



MINERAL-ELEVATOR.

that shown in *Fig. 4* must have double strands of chain, placed one on each side of the buckets, so that the guide-wheels which curve

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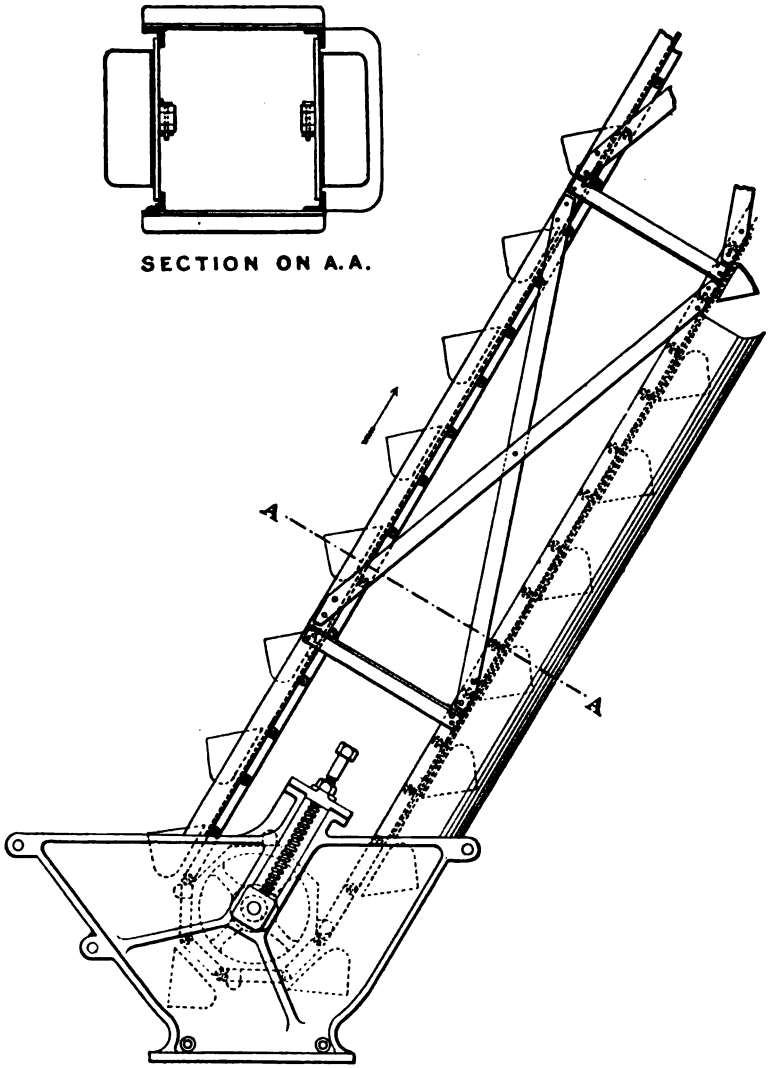
the chain shall not foul the buckets. Similar elevators are made with single strands of chain having skidder-bars which slide

Figs. 3.



MINERAL-ELEVATOR.

round two angle-bar curves, instead of over the guide-pulleys; but this plan is advisable only in small elevators.

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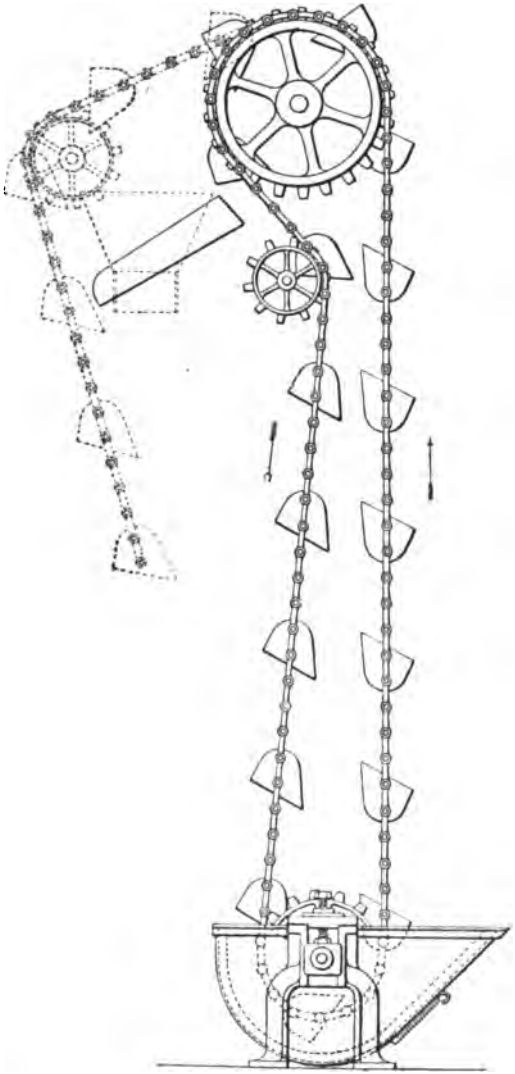
A rational form of elevator is one fitted with a continuous train of buckets, without gaps between them. This kind is of much

Fig. 4.



MINERAL-ELEVATOR.

larger capacity than an ordinary elevator of the same dimensions. It takes and delivers its load more uniformly; and as the buckets

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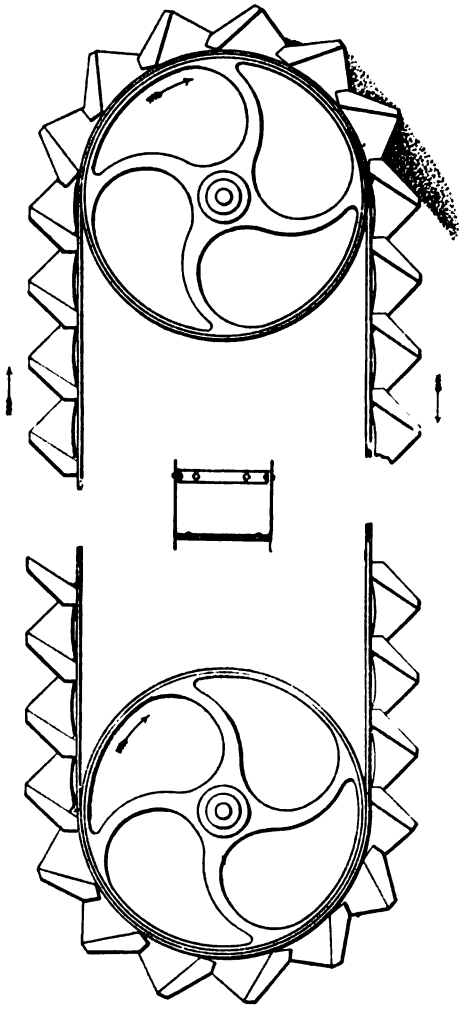
do not plough intermittently through the contents of the elevator-well, slightly less driving-power is required for equal delivery. *Figs. 5* show such an elevator for grain, and *Figs. 6* for minerals.

Figs. 5.



CONTINUOUS GRAIN-ELEVATOR.

Gear-Drives for Elevators. — For large elevators—especially where limited space does not allow the internal elevator-pulleys (sprocket or polygon wheels) to be large enough in diameter—spur- or bevel-wheels having a ratio of 1:2 to 1:3 should be employed, together with a suitable counter-shaft.

Power required for Elevators. — This depends on the height of the elevator and the weight to be lifted; and practically not less than twice the theoretical horse-power should be allowed.

Spouts and Shoots.— The spouts and shoots which receive the delivery from elevators should always be of stout wrought iron, or better still of cast iron, in the immediate proximity of the elevator. For small grain-elevators, wood with a sheet-iron lining will be found sufficient. It is surprising how quickly even cast-iron shoots are worn through by the constant impact of grain, to say nothing of heavier and harder substances. A sheet of india-rubber

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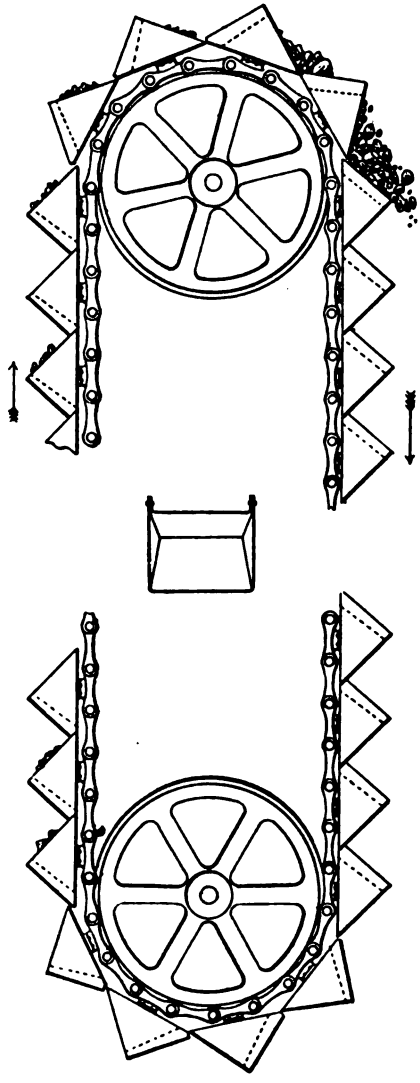
about ½ inch thick, secured at the place of impact, will last much longer than a cast-iron plate of the same thickness. The shoots themselves should be at an inclination, say, 10 per cent. steeper than the angle of repose of the different materials.

Figs. 6.



CONTINUOUS MINERAL-ELEVATOR.

II. CONVEYORS.

Screw or Worm Conveyors.—Conveyors are of numerous kinds. Some, although of great antiquity, are still employed, and answer their purpose even better than more modern appliances. The oldest conveyor is undoubtedly the Archimedean screw or worm conveyor, consisting of either a continuous or segmental screw-blade round a spindle. The screw is made to revolve in a suitable trough, along which it thus propels the material slowly.

The first of such conveyors were probably used in the earliest flour-mills, and were made by driving hardwood blades having pegs on one end into a soft wooden spindle. Such a segmental worm is illustrated by *Figs. 7*. Later the worm was made in a better form by threading cast-iron sections on a square iron shaft, which was turned at intervals of 6 feet to 10 feet to form

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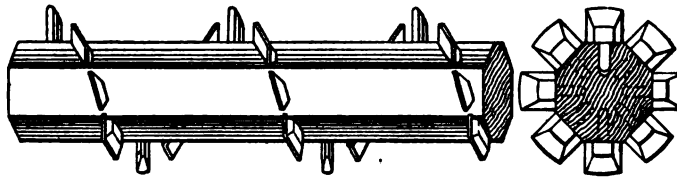
suitable bearings. *Figs. 8* show such a conveyor. Still later constructions, in use at the present day, are illustrated in *Figs. 9, 10* and *11*. *Figs. 10* represent a so-called "paddle worm," constructed

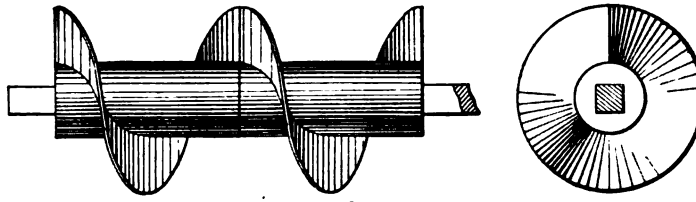
Figs. 7.



EARLY FLOUR-MILL CONVEYOR.

of a series of blades forming together as nearly as possible a complete screw. Each of the blades is fixed to the central shaft or spindle by a shank, which is screwed and fitted with a nut. The

Figs. 8.

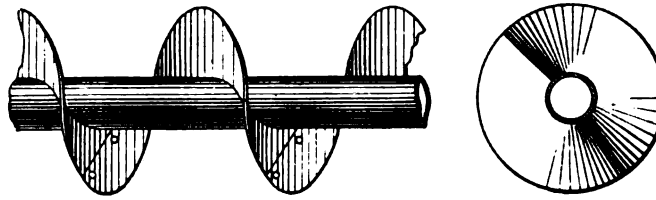


SCREW CONVEYOR.

spindle is made of steam-pipe in lengths of about 8 feet, coupled together by turned gudgeons, which answer at the same time as journals for the bearings.

The continuous worm is illustrated in *Figs. 9:* the only differ-

Figs. 9.



CONTINUOUS WORM CONVEYOR.

ence between it and the paddle-worm conveyor is that the screw is not composed of separate blades, but is one continuous sheet-iron spiral, which is secured to the spindle at intervals more or less frequent, according to the size and capacity of the worm.

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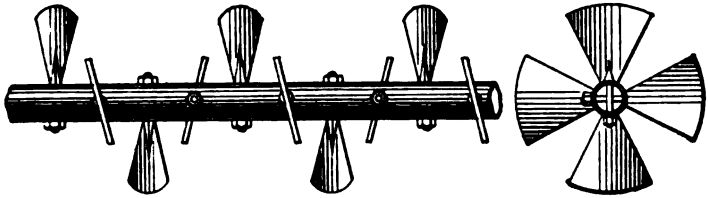
The best method of construction is to cut a narrow spiral groove in the spindle, and secure the sheet-iron spiral in the groove.

A fourth form of worm, which ought to come under this heading, is the spiral or so-called anti-friction conveyor, illustrated in *Figs. 11.* It was introduced about 10 years ago, and is a simple kind of conveyor. It is inexpensive in first cost, as the spirals

Figs. 10.

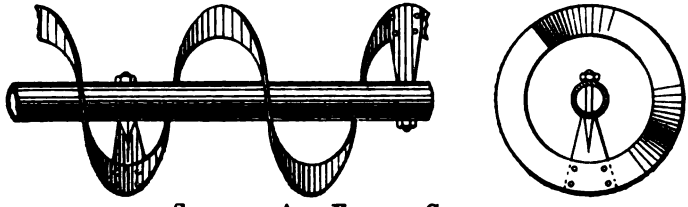


PADDLE-WORM CONVEYOR.

which form the principal part are made by machinery. The illustration shows the mode of fixing the spiral to the spindle. The spiral is made of various shapes, from a round bar about ½ inch in diameter to L or T section. The best form, however, is a flat bar.

In all worms the ratio of the diameter to the pitch depends upon the kind of material to be conveyed. It ranges from 3 : 1 to a pitch equal to or even larger than the diameter of the worm. The greater the pitch, the greater is the driving-power required. It is

Figs. 11.



SPIRAL OR ANTI-FRICTION CONVEYOR.

therefore usual to employ for heavy materials, such as cement, worm conveyors with a small pitch, and for grain those with a larger pitch.

The following Table shows the capacity of worm conveyors of different diameters, with their respective speed and pitch, the latter being half the diameter; the capacity is given for continuous, and for paddle and spiral conveyors. Obviously the

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capacity of the continuous worm is greater than that of the paddle or spiral conveyors; the two latter are about equal in capacity, if other conditions are equal.

CAPACITY OF WORM CONVEYORS.

Diameter of Blade.	Pitch.	Diameter of Hollow Spindle.		Revolutions per Minute.	Delivery per Hour.	
		Inner.	Outer.		Continuous Worm Conveyor.	Paddle and Spiral Worm Conveyors.
Inches.	Inches.	Inches.	Inches.	Revs.	Cubic Feet.	Cubic Feet.
4	2	1	1⅜	130	55	45
6	3	1½	1⅝	120	150	125
8	4	1½	1⅝	100	300	250
9	4½	1½	1⅝	100	480	400
10	5	2	2 7/16	90	600	500
12	6	2	2 7/16	90	1,000	825
14	7	2	2 7/16	80	1,400	1,150
16	8	2	2 7/16	70	1,900	1,575
18	9	2	2 7/16	60	2,300	1,900

Conveyors of double pitch have twice the capacity, and, if more than 9 inches in diameter, should be driven by means of gearing and countershaft, unless they are very short.

Worms are fitted into a wooden or iron trough so as to leave a clearance of between ⅛ inch and ¼ inch. The successive lengths are supported at intervals of 8 feet for 4-inch worms, 8 feet to 10 feet for 6-inch to 10-inch worms, and 10 feet to 12 feet for 12-inch to 18-inch worms. A continuous worm is stiffer in itself than a paddle worm, and may therefore be in longer lengths, *i.e.*, with fewer intermediate supports.

A detail of great importance in all worm conveyors is the intermediate bearing. If cumbersome it obstructs the passage of the material, and forms an obstacle which must be carefully avoided; and as all such intermediate bearings which are in halves are necessarily bulky, it is preferable to choose whole bearings, although they lack some advantages which those in halves possess. The most satisfactory intermediate bearing is a small phosphor-bronze bush, carried by a short piece of pipe which is screwed into a cast-iron support overhead and secured by a lock-nut. The bearing can be oiled through the pipe. *Figs. 12* show such a bearing, and *Figs. 13* a simple form of adjustable bearing in halves.

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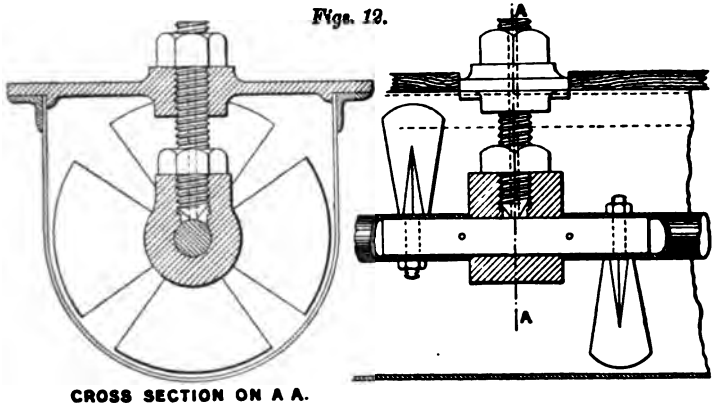
Delivery of the material from a worm conveyor can be effected at any number of points: all that is necessary is to provide a suitable outlet. The outlet should be as long and as wide as the diameter of the worm, if it is intended to get the whole of the

Figs. 12.

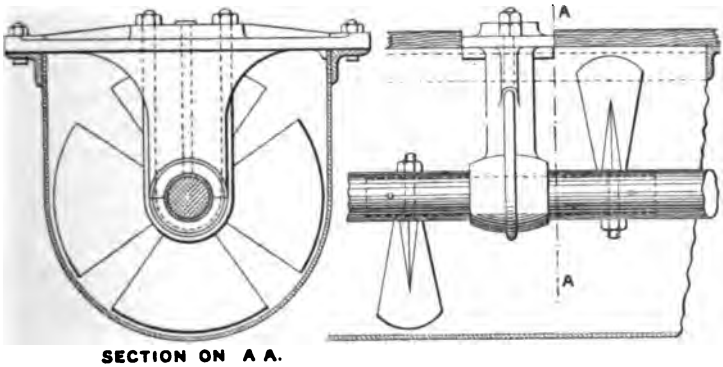


CROSS SECTION ON A A.

INTERMEDIATE BEARING FOR WORM CONVEYORS.

feed through it. The worm delivers only on its leading side. The lid which covers the worm-box or trough should not be fixed, but should lie loose on top; for, in the event of an accumulation of material occurring through the blockage of a spout, unless the

Figs. 13.



SECTION ON A A.

INTERMEDIATE BEARING FOR WORM CONVEYORS.

material in the worm can force the lid open and throw the material on the floor, the worm will be stripped if it is continuous, or be broken if it is of the paddle kind.

The tubular worm conveyor deserves to be mentioned in this category; for, although it is not often used, under some conditions

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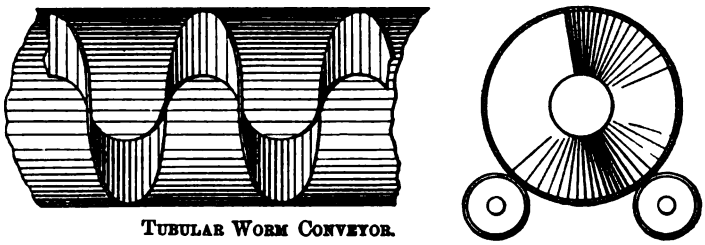
it is useful. It consists of an iron tube fitted with an internal continuous spiral, as shown by *Figs. 14.* When at work it revolves bodily on suitable rollers. This conveyor is more expensive and needs more driving-power than an ordinary worm. Moreover, unless its speed is within the correct limits, the capacity diminishes, as the centrifugal force counteracts the propulsion; for with this appliance the conveying is done by gravity. The following experiment was made with a tubular worm 6 inches in diameter and of 2-inch pitch, with 2½ inches depth of blade. At 60 revolutions per minute it delivered at the rate of 28 cubic feet per hour, at 80 revolutions 36 cubic feet, at 100 revolutions 30 cubic feet; at 140 revolutions per minute it ceased delivering altogether, the grain being simply carried round and round in the tube. A further experiment with a 12-inch worm of 4-inch pitch and 12 feet long, showed 60 revolutions per minute as the maximum effective

Figs. 14.



TUBULAR WORM CONVEYOR.

speed, at which grain was delivered at the rate of 6·75 tons per hour. The power required was 0·04 HP. per lineal foot. The best pitch for these conveyors is two-fifths of their diameter.

A situation in which the tubular worm conveyor is very useful is where grain, etc., has to be conveyed from one building to another on the same level, and where no bridge is available, to which any other kind of conveyor could be attached. The tube can be made as strong as necessary, and be stiffened by a spider in the middle and a number of tie-rods, as shown in *Fig. 15.*

Power required to drive Worm Conveyors.—For the sake of easy comparison with other conveyors, this is based on a load of 50 tons of grain per hour, to be conveyed a distance of 100 feet. An 18-inch or 20-inch continuous worm will do the work if driven at 60 revolutions per minute, and the power required will be 18½ HP. to 19 HP. To convey cement would require somewhat more power, on account of the greater friction against the worm-blades and trough.

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The principal advantages of a worm conveyor are its great simplicity and small first cost. The terminals are much less

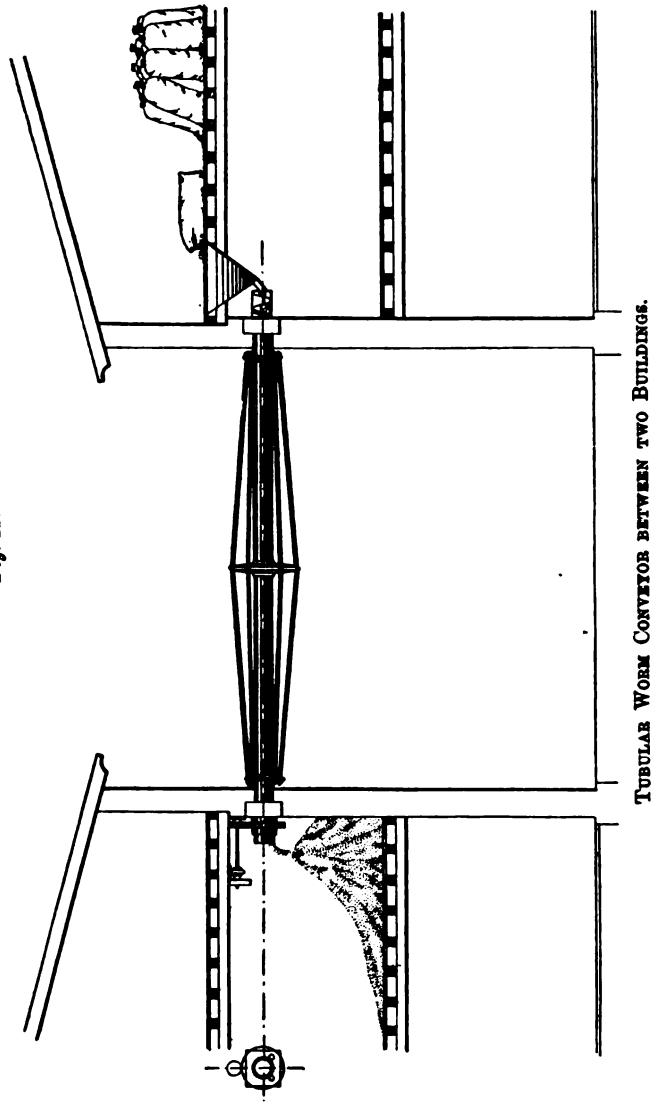

Fig. 15. TUBULAR WORM CONVEYOR BETWEEN TWO BUILDINGS.

expensive than those of any other kind of conveyor. Short worm conveyors can therefore be procured at a much smaller cost

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than short conveyors of other types. Worm conveyors are of great service where a mixing of the material conveyed is also desired. For example, where cement and sand in a dry state are conveyed together, they will arrive at the delivery end well mixed. The disadvantages are the large amount of driving-power required, the grinding action on the material to be conveyed, and great wear and tear of the conveyor if used for hard and cutting substances.

Push-plate Conveyors.—The next to be considered are drag- or push-plate conveyors. They vary considerably in minor details of construction, but in principle they consist of a fixed, open trough formed of stout sheets of iron or steel, and often of cast iron. The material to be conveyed is fed into the trough, and is dragged or pushed along by a series of plates attached to an endless chain, which, with its attachments, revolves over terminal pulleys, so that only half the chain is at work at a time. *Figs. 16* show a portion of an ordinary push-plate conveyor in two views. The chain should be attached as nearly as possible to the centre of the push-plates, which are not allowed to touch the bottom of the trough. For this purpose they are fitted, like the buckets of elevators, with a skidder-bar which slides on well-greased angle-bars forming portions of the framework. Sometimes, instead of skidder-bars, there is a pair of small wheels or rollers running on corresponding channel- or angle-bars: this is a good plan, as it requires less driving-power. In other cases the bottom of the cast-iron trough of a push-plate conveyor is made with a projecting and renewable ridge along which the chain slides. This construction is a very good one, as the chain pulls its load at or near the centre of the push-plates and not, as in the former case, above it. *Figs. 17* are two views of such a conveyor.

Much of what has been said in reference to elevators applies also to push-plate conveyors, which are so simple that they require little further description. In *Figs. 16* and *17*, the return strand of the conveyor is shown beneath the conveying strand. Their positions must be reversed if the load has to be delivered at intermediate points; otherwise the spouts leading the material away would foul the return strand.

Capacity of Push-plate Conveyors.—This depends upon size of trough, pitch of plates, and speed of travel. The pitch of the plates ranges from 18 inches to 3 feet, and the speed of travel from 60 feet to 180 feet per minute. For coke and other friable substances the speed should not exceed 60 feet to 99 feet per minute; where breakage of the material is of minor

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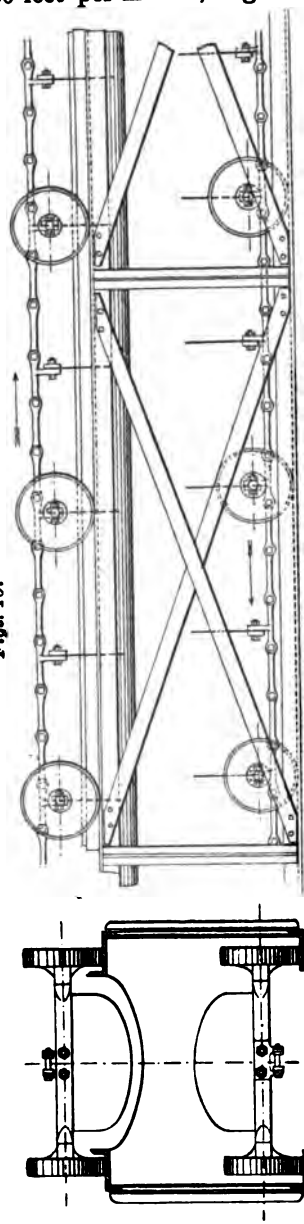
consequence, the maximum speed, 180 feet per minute, might be employed. For example, a conveyor with a trough 24 inches wide, having the plates 24 inches apart, and running at a speed of 100 feet per minute, will convey 30 tons of coal per hour. Another push-plate conveyor, with a steel trough 20 inches wide, with the plates 18 inches apart, and running at a speed of about 180 feet per minute, has a capacity of 40 tons of coal per hour. A push-plate conveyor for hot coke with a 27-inch trough and with malleable-iron plates 24 inches apart, running at about 48 feet per minute, delivers about 20 tons of coke per hour.



Figs. 16. PUSH-PLATE CONVEYOR WITH CHAIN ABOVE TROUGH.

Power required to drive Push-plate Conveyors. — This depends upon the nature of the material conveyed, and upon the condition of the trough. For example, cement-clinker and coke would require more power for their conveyance than would coal; but as the push-plate conveyor is altogether unsuited for hard and cutting substances, on account of the great wear and tear, the following figures are based on coal-conveying. A push-plate conveyor, 100 feet long, conveying coal at the rate of 50 tons per hour, will require a driving-power of 12 HP.

Cable Conveyor.—The cable conveyor is for special work, and consists of a V or U-shaped wooden trough, through which is dragged a wire rope with disk-like attachments. The trough is sometimes lined with sheet iron,

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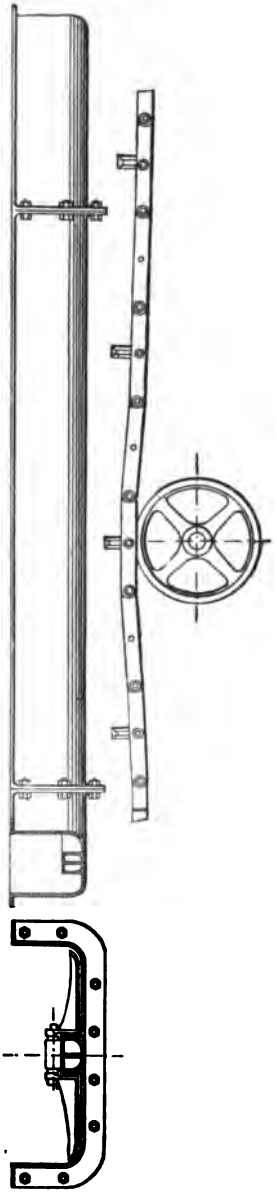
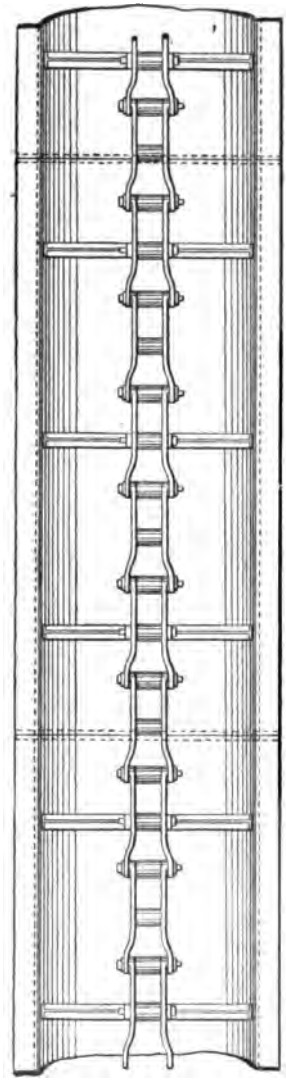
according to the nature of the material to be conveyed. Such



Figs. 17.



PUSH-PLATE CONVEYOR WITH CHAIN IN TROUGH.

conveyors are suitable for the conveyance of light and bulky

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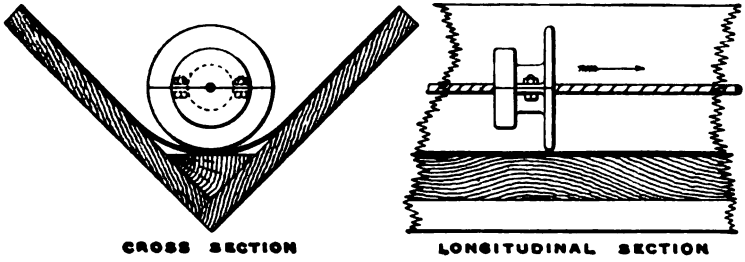
material, preferably in a straight line and down an incline. They would be suitable for timber blocks, chips, shavings, peat, pulp, hay, etc. *Figs. 18* and *19* show two longitudinal and two cross sections of cable conveyors. The speed of travel is 100 feet to 120 feet per minute.

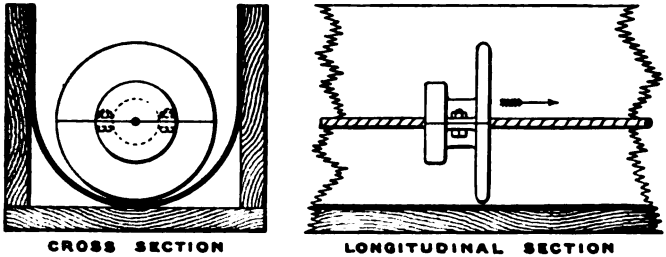
Figs. 18.



CABLE CONVEYOR WITH V-SHAPED TROUGH.

Band Conveyors.—Band conveyors were introduced more than 30 years ago,[1] and now form one of the best means of conveying large quantities of material of almost any kind, especially over long distances. They consist of a band of canvas, woven wire, or india-rubber with insertion, which runs over two terminal pulleys and is supported by a series of intermediate rollers, which are placed

Figs. 19.



CABLE CONVEYOR WITH U-SHAPED TROUGH.

at shorter intervals under the loaded than under the empty side. Such conveyors are frequently fitted with some kind of tightening-gear to keep the band in tension. Early band conveyors were used almost entirely for conveying grain, and for this purpose they have now practically superseded all older conveyors for distances of more than about 50 feet.

[1] Proceedings Institution of Mechanical Engineers, 1869, p. 214.

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Like other mechanical innovations, the band conveyor had to pass through a period of disappointments. It was feared that a flat band would spill the grain, and the supporting rollers were therefore hollowed in the middle, so as to give the band the form of a trough. This was satisfactory as far as the conveying was concerned; but the bands employed, which were of cotton webbing covered with india-rubber, wore out in a very short time; for owing to the varying diameter of the curved roller, and the consequent different circumferential velocities at different points of it, a destructive rubbing action was set up between roller and band, the latter having, of course, the same velocity over the whole of its width. Not until later did experiment show that grain would lie and be conveyed well on a perfectly flat band, if it was properly delivered thereon, that is, at the speed at which the band was travelling. At the present time the band conveyor for grain usually runs perfectly flat, except at points where grain is fed on to it; here two separate curving-rollers are applied, which slightly hollow the band for a few feet, and then allow it to lie flat again on its supporting rollers.

The supporting rollers are 4 inches to 6 inches in diameter and are sometimes made of wood; but more often they are steel tubes to which are secured spindles with conical end gudgeons. The gudgeons run in suitable bearings, which must be well lubricated. Such rollers are used at intervals of 6 feet along the upper or working portion of the band, and 12 feet apart along the lower or return portion. Sometimes it is desirable to use both top and bottom portions for conveying, in which event the supporting rollers for the bottom band must be as close together as those for the top; moreover, the terminal pulleys must be much larger than usual, in order to allow a greater distance between the two bands and thus give sufficient space between them for spouting the material on to the lower span and off again at the other end. The two portions can run at any distance apart by using two additional terminal rollers, as shown in *Fig. 24*. Thus one portion may run along the top floor of the granary, while the other travels along the bottom floor. Throw-off carriages are indicated on both top and bottom bands. Supporting rollers for a grain-conveyor are shown in *Fig. 20*. For short lengths the tightening of a band conveyor is done in a similar manner to the tightening on elevators, *i.e.*, by means of two screws, which push the two pedestals of one terminal pulley farther away from the other terminal; but as such an appliance does not admit

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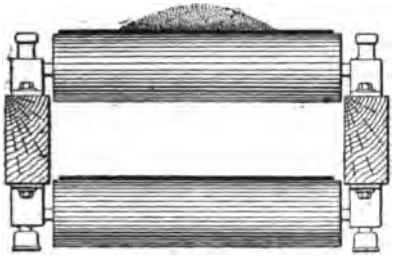
of great range, it is insufficient for long conveyors, and in these the tightening-gear consists of a jockey pulley loaded with weights, riding in a loop of the band. It can be placed

Fig. 20.



at any point in the return half of the band, but is generally situated at the end opposite to the driving-pulley of the conveyor. *Fig. 21* shows a terminal tightening-pulley; while

Fig. 21.

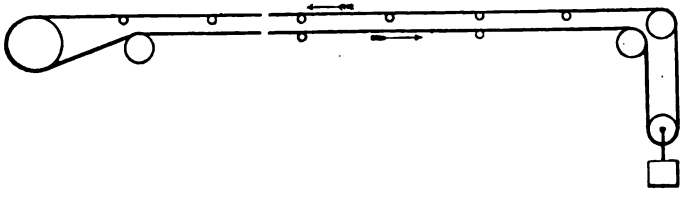
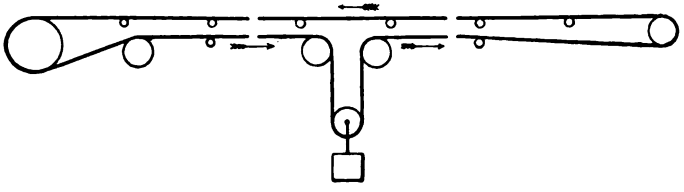


Fig. 22 shows a method by which the pulley can be applied to any part of the returning band. The tight side of the band should preferably be used for conveying, as it is always in a flatter condition than the other.

Fig. 22.



For drawing off the feed of a band conveyor at an intermediate point, a throw-off carriage is employed. It consists in principle of two guide-pulleys, having their bearings in a frame

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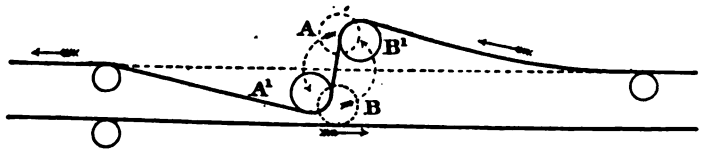
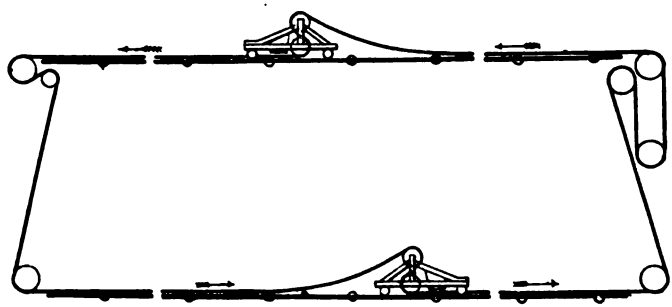
which by a worm and worm-wheel can be turned round a common centre in the carriage. When out of use, one guide-pulley is above and the other below the band, which runs through between them without touching them. If delivery of the material is required at a certain point, the carriage is pushed into position, and the guide-pulleys are turned round the common centre in the direction of the arrow, so as to raise one part and lower

Fig. 23.



the other part of the band, as shown in *Fig. 23;* the dotted circles A, B, represent the guide-pulleys when out of use, while the full circles A^1, B^1, show their respective positions when in use. As soon as the grain arrives at the upper pulley, it is thrown by its own momentum, and is received in a hopper, which forms part of the throw-off carriage; it is then led off sideways through a spout, so as to clear the band. The throw-off carriage

Fig. 24.



shown in *Figs. 25* is of a simple kind, without adjustment. It has a clamp by means of which it can be secured in position. The diagram shows also the hopper for catching the grain and the alternative spouts, with flap-valve for directing the delivery to either side.

All band conveyors which are intended for intermediate delivery have to be fitted with a tightening-gear, as shown in either *Fig. 21*

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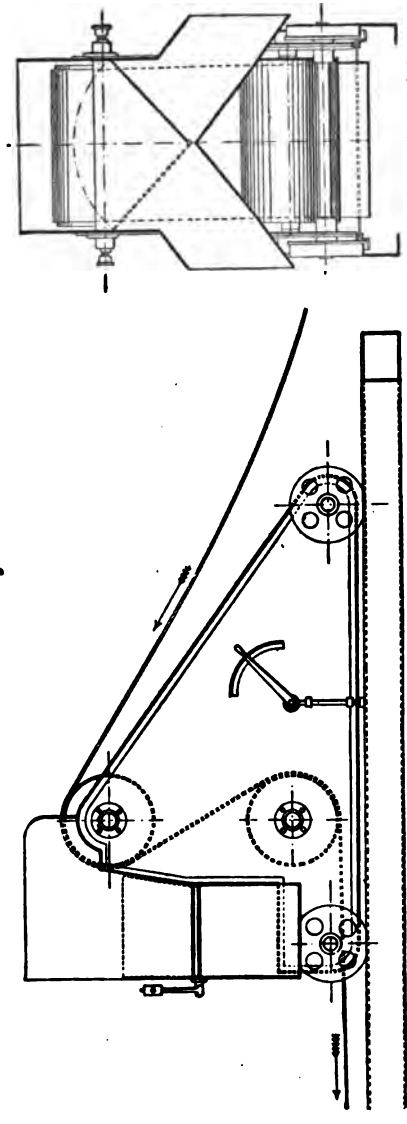
or *Fig.* 22, because the use of the throw-off carriage necessitates additional length of conveyor-belt, which must be taken up when-



Figs. 25.

ever the carriage is out of use; and the tightening-arrangement provides a suitable place for the extra length of band.

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The speed at which band conveyors run varies for grain between 450 feet and 600 feet per minute. The lower speed is for oats or other grain containing a quantity of chaff and hulls, which would be blown off the band at a speed exceeding 500 feet. Wheat and barley are generally conveyed at a speed of 500 to 550 feet per minute; while maize, beans and heavier seeds are conveyed at the maximum speed of 600 feet per minute.

The approximate capacity of band conveyors 8 inches to 24 inches wide is given in the following Table, in tons per hour, for different speeds:—

SPEED AND CAPACITY OF BAND CONVEYORS.

Width of Band.	Speed and Capacity of Band.		
	450 Feet per Minute.	500 Feet per Minute.	600 Feet per Minute.
Inches.	Tons per Hour.	Tons per Hour.	Tons per Hour.
8	6	7	8
10	9	10	12
12	18	20	22
14	26	30	34
16	36	40	44
18	45	50	55
20	60	65	70
22	70	80	90
24	90	100	110

For conveying grain less power is required by a band conveyor than by any other. An 18-inch band at 500 feet per minute would convey 50 tons of grain per hour, and if it were 100 feet long it would require 4·5 HP.

Band conveyors for heavier materials, such as coal, coke, minerals, etc., are similar to those already described, with the exception that the fittings throughout are much more substantial. The band itself is stronger, so as to bear the greater weight and also the strain on the part where the feed is received; consequently special attention is paid by the best makers to the middle portion of its width, which is subjected to the greatest wear and tear, while the edges suffer but little wear. The bands are therefore made of insertions covered with india-rubber—at least over the portions which run on the rollers; while the top, which carries the load, is of solid india-rubber, extending for nearly half the thickness of the band, and tapering off towards its edges.

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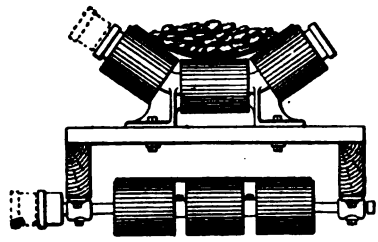
The carrying rollers are always so arranged as to curve the top or leading portion of the band into a trough-shaped groove, which is done by arranging either two or three rollers on each pedestal. *Fig. 26* shows one of these supports for both top and bottom bands, consisting of six rollers. The bottom band is sometimes supported by single rollers, as in grain-conveyors. As there is sometimes a tendency for the band to move sideways on its rollers, so that the centre of the band is not over the centre of its supports, occasional smaller rollers are employed to keep it central.

Fig. 26.



The speed of band conveyors when used for minerals varies within wide limits, according to the nature of the minerals. It is not so much the specific gravity which determines the speed, as the size of the pieces to be conveyed. The best speed for large pieces is 150 feet to 200 feet per minute; and the speed increases as the size of the material decreases, up to a maximum speed of 500 feet to 600 feet per minute.

Band conveyors may be used to convey uphill at any inclination up to 26° from the horizontal, without affecting their capacity.

The following Table gives the approximate capacity, in tons of coal per hour, of horizontal bands of different widths, with their respective speeds and the brake horse-power required for lengths of 100 feet:—

SPEED AND CAPACITY OF BAND CONVEYORS FOR COAL.

Width of Band.	Speed.	Capacity for Coal.	Size of Coal.	Brake HP. for Conveyor 100 Feet long.
Inches.	Feet per Min.	Tons per Hour.		B.HP.
12	150 to 600	10 to 35	From 2-inch cubes to dust	3·2
18	„ „ „	50 „ 175	„ 4-inch cubes to ¾-inch cubes	4·8
24	„ „ „	125 „ 475	„ 6-inch „ 1-inch „	6·0
30	„ „ „	250 „ 900	„ 7-inch „ 2-inch „	7·6
36	„ „ „	350 „ 1,500	„ 9-inch „ 2-inch „	9·2

If the band is inclined, the power increases accordingly.

Advantages and Disadvantages of Band Conveyors.—The principal advantage is the small amount of power required for driving. Band conveyors do not injure the material conveyed, their wear and

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tear is comparatively small, and they work noiselessly. The disadvantages are: the feed cannot be withdrawn at intermediate points without the use of the somewhat cumbersome throw-off carriage; and as a rule the feed and the conveyor have to be stopped if the delivery of the band is to be changed to a different point. Another drawback is that many small bearings have to be oiled and kept in repair, and as the rollers make 150 to 600 revolutions per minute, they require considerable attention.

Continuous-Trough or Travelling-Trough Conveyor.—This is intermediate between the band conveyor and the vibrating-trough conveyor. It consists of an endless trough made up of short sections which are riveted to the links of suitable endless chains travelling over two terminal pulleys, one of which is adjustable to take up the wear in the joints of the chain. The whole is similar in construction to the push-plate conveyor, each length of trough taking the place of a push-plate. The sections of trough are also sometimes fitted with small supporting rollers, which run on angle-bars, as in the push-plate conveyor. These travelling-trough conveyors are better than push-plate conveyors, as they take less power, and do not damage the material by breaking it. With this class of conveyor, however, intermediate delivery is altogether excluded. The travelling-trough conveyor is often used as a picking-table for sorting materials as they pass; and it occasionally takes the place of a band conveyor when the material conveyed would injure an india-rubber band. *Figs. 27* show a portion of such a conveyor, which explains itself. The speed of travel, namely, 60 feet to 120 feet per minute, is somewhat less than that of push-plate conveyors. The capacity is easily found by multiplying the cross-sectional area of the trough by the speed.

Vibrating-Trough or Swinging Conveyor.—This latest kind of conveyor consists of troughs which receive at one end the material to be conveyed, and transmit it to the other end by means of a succession of suitable forward and backward movements of the troughs. It may therefore be classed with the two previous kinds, namely, the band and the travelling-trough conveyor, because in all three the material is virtually conveyed in a trough without the use of the stirring or pushing element which is a feature of worms and of push-plate and cable conveyors. It is obvious that materials which deteriorate through rough treatment should be conveyed by appliances of these three classes.

There are several varieties of the vibrating-trough conveyor. In some the reciprocating movement of the trough is effected by means of a crank and connecting-rod, while the trough itself is

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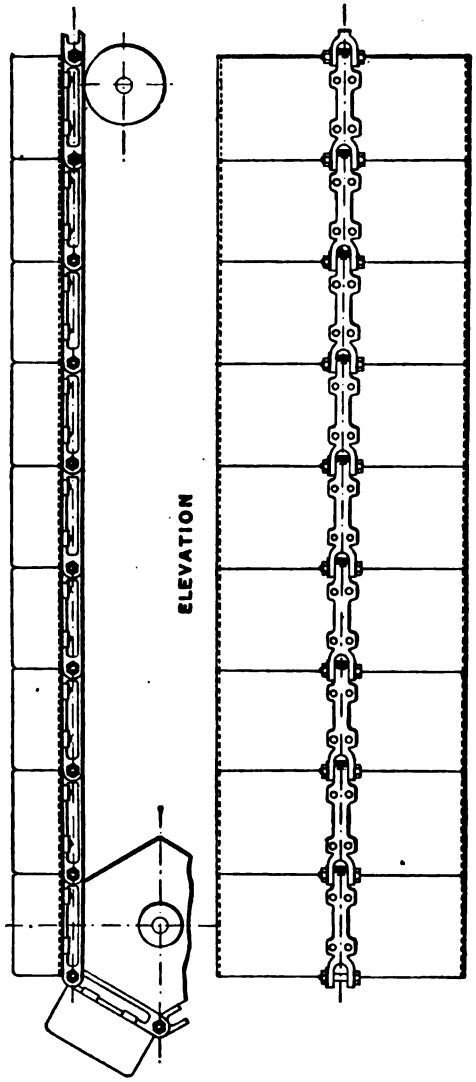
supported on rollers or portions of rollers; in others the trough is actuated by a cam, or by cranks with some kind of quick-return motion.



Figs. 27. Continuous-Trough Conveyor.

Instead of by rollers the trough is more often supported in its reciprocating movement by links and by flexible legs placed in an oblique position; for two reasons. First, the spring legs are

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securely bolted at one end to the floor or other support, and at the other to the conveyor-trough itself, and consequently they require no lubrication. Secondly, the combination of the reciprocating motion of the trough with the rocking of the flexible legs causes the material to travel faster in the trough, for a given stroke of the crank, than with any other mode of support.

The swinging conveyor is built on this plan and the diagram in *Figs. 28* illustrates the principle of its action. The diagram is greatly exaggerated, as the movements are too small to be shown to a small scale. The line A B represents the bottom of the trough, and C, C, are two of the spring legs. The full lines show the legs at the extreme backward position of the crank D, and the dotted lines show the forward position of the crank. At the moment the trough moves forward and upward, E, the object to be conveyed, is thrown also forward and upward, approximately at right angles with the slanting legs C, C; and before it has time to complete its short parabolic course to E_1 the trough has been moved back by the crank into the original position so as to receive it. The same process is repeated again and again, and the progress of the object is indicated by E_1, E_2, and E_3. The actual horizontal movement of the trough is only about 1 inch, and the vertical height between the dotted and the full lines A B is only $\frac{1}{8}$ inch. If the trough is full, the material moves, as it were, in a solid mass. There is no friction between the particles of material, nor between the trough and the material, as it is a hopping and not a sliding motion which takes place.

Figs. 28 show in elevation and in section a conveyor of this kind, which would be suitable for lengths up to 50 feet and for widths up to 24 inches. For longer lengths and for greater capacities, the conveyors are balanced, *i.e.*, they are divided into two sections, one of which works at a level about 2 inches higher than the other, and delivers into the lower. They are actuated by a double or multiple crank, the centres of which are at about 180° to each other, so that as one section of the conveyor moves forward the other half moves backward; and at the same time the material is kept moving forward in the same direction, as all the spring legs are similarly inclined. Such a balanced conveyor is illustrated in *Figs. 29*.

Figs. 30 show a similar arrangement of balanced conveyor, the two sections of which work at right angles, one half balancing the other. Ordinary balanced conveyors are necessarily driven at or near the middle of their length. When this is not convenient, they may be driven at one end as shown in *Figs. 31*.

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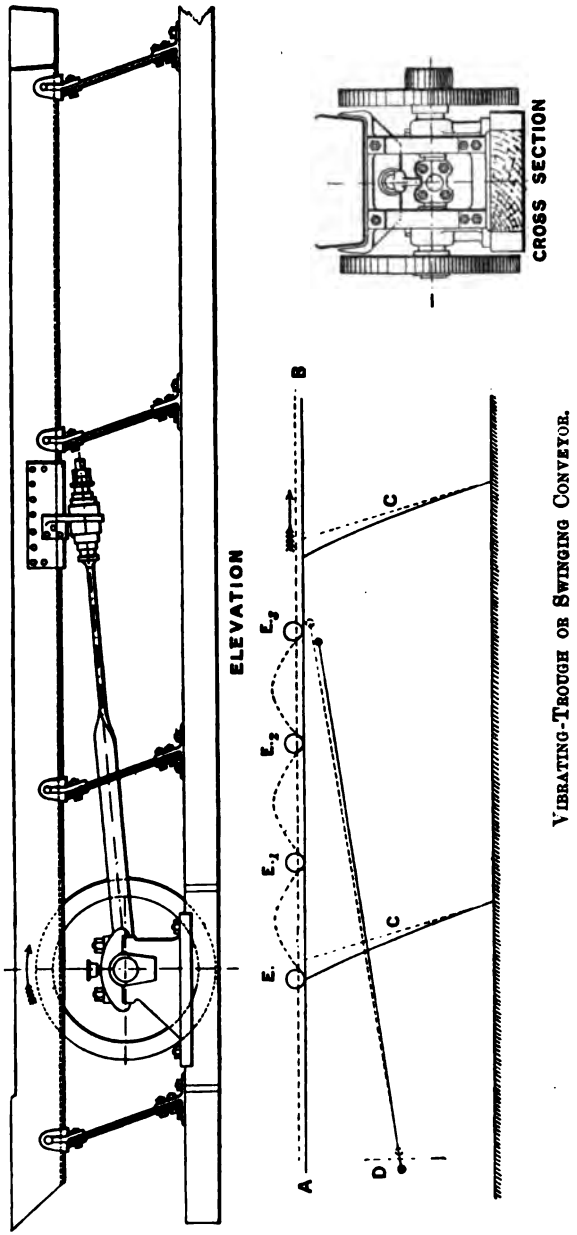

Figs. 28.

VIBRATING-TROUGH OR SWINGING CONVEYOR.

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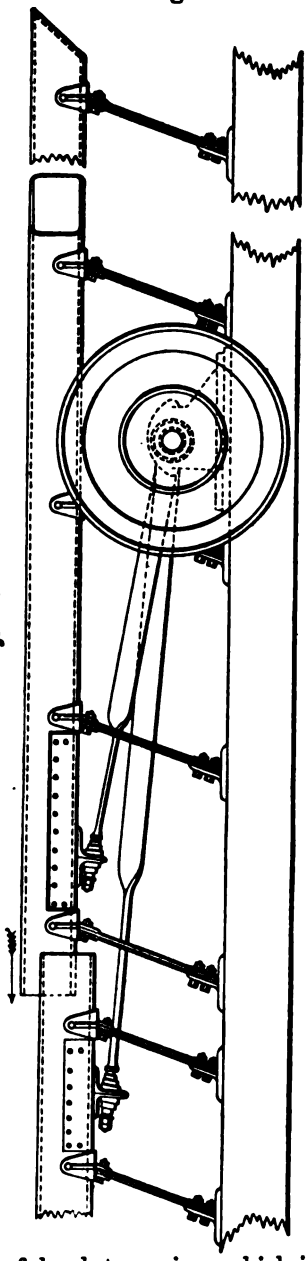
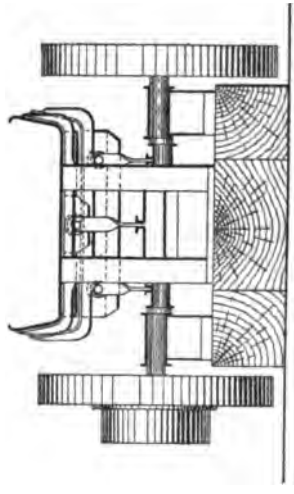
Here the balancing of the conveyor is effected by means of a





Figs. 29. BALANCED SWINGING CONVEYOR.

powerful volute spring, which is compressed and released by one

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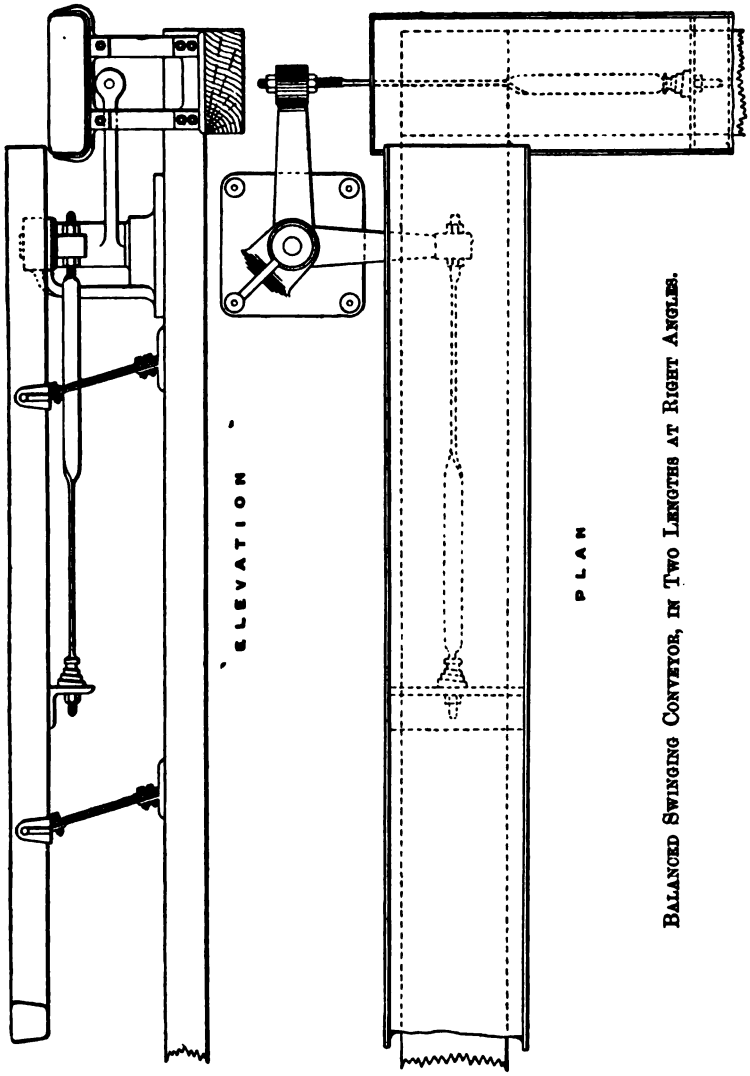
of the cranks and connecting-rods, instead of being coupled to one half of the conveyor.

The swinging conveyor can be used to work partly in one direc-



Figs. 80.

BALANCED SWINGING CONVEYOR, IN TWO LENGTHS AT RIGHT ANGLES.

tion and partly in another, by simply reversing the slant of the spring legs, and by joining the trough at the junctions by a flexible connection. The load can be fed into or withdrawn from

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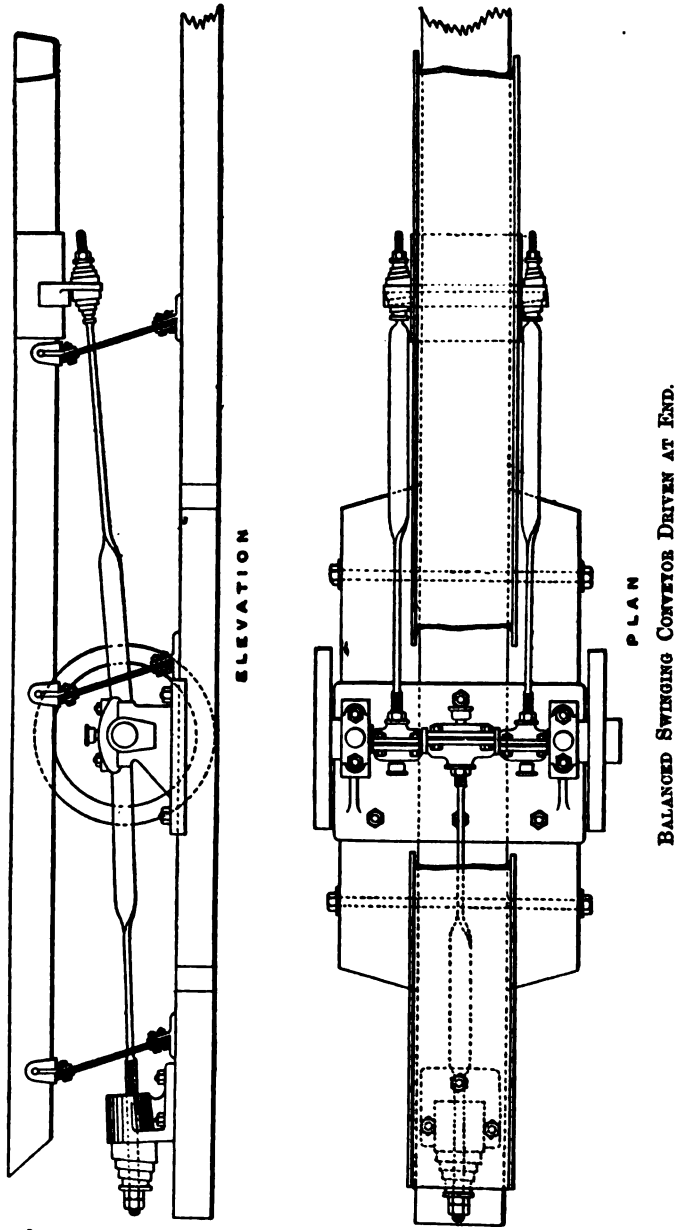
any of these conveyors at any number of points, without cessation



Figs. 31. Balanced Swinging Conveyor Driven at End.

of work. The rate of travel of the material varies between 40 feet

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and 70 feet per minute when the conveyor is driven at 300 to 350 revolutions per minute. The connection between the trough and the connecting-rod is not rigid, but two very strong volute springs are placed on either side of the attachment. This is for the purpose of allowing the trough itself to exceed the stroke of the crank by a fraction of an inch on either side; as the radius of the crank is generally less than ½ inch, the total travel of the trough at each revolution is only about 1 inch. There appears to be no limit to the length or width of conveyors of this class: they are at work in lengths of 300 feet and as wide as 6 feet 6 inches, and there is no apparent reason why these dimensions should not be exceeded. The success of the swinging conveyor is largely due to its simplicity, and to the small driving-power required, especially when the balanced drive is fitted, because then half the spring legs are always in tension while the other half are relaxed: so that the power which has been exerted in bending half the legs is given back in bending the other half immediately on the crank passing the dead centre.

The following Table gives the capacity, in tons of coal per hour, of conveyors working horizontally with troughs of various sizes:—

CAPACITY OF SWINGING CONVEYORS FOR COAL.

Depth of Trough.	Width of Trough in Inches.								
	12	14	16	20	24	36	48	60	72
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
4 inches	6–7	7–8	8–9	10–12	13–15	..	..	..	..
6 „	9–10	12–13	13–15	16–18	18–20	30–32	35–40	45–50	50–60
8 „	..	..	..	..	25–30	35–40	50–60	60–70	70–80

A downward slope of only 5 per cent. will increase the capacity of a swinging conveyor about 10 per cent., while an upward slope will reduce it correspondingly. A horizontal swinging conveyor 100 feet long, conveying a load of 50 tons per hour, will require 8·75 HP.

The advantages of swinging conveyors are:—they will convey any kind of material in large or small pieces, and, however friable the material may be, they will not break it, and therefore will not cause dust; by the use of ordinary slides in the bottom of the trough, the material can be withdrawn at any point or points; and further, there are only two bearings and one or two cranks to be oiled and kept in repair, whatever the length of the conveyor may be. They have but one disadvantage (which applies only to

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conveyors without the balanced drive), namely, they are apt to impart some slight vibration to the structure, if fixed, say, in a light roof, and if longer than 50 feet. If these conveyors are balanced, however, there is no more vibration than with ordinary machinery in motion.

A complete and compact coal-handling plant is shown by Figs. 32, Plate 2, which illustrate the installation at the Brentwood Gasworks. The coal is received in railway trucks, which are emptied by means of the hydraulic tilting-gear into an iron hopper, whence it passes through a pair of breaking-rollers to the elevator, which in its turn delivers the coal through a swinging conveyor either into the coal-store, or into a series of hoppers from which the supply for the retorts is drawn. When the hoppers are empty, coal can be drawn from the store by means of a second swinging conveyor in the tunnel below the store, and be passed again to the elevator and conveyor to replenish the hoppers.

Power Required for Different Classes of Conveyor.—The following Table gives a summary of the power required for driving the principal conveyors for capacities of 50 tons per hour and for lengths of 100 feet:—

	HP.
Band Conveyor for Grain	4·8
„ „ „ Minerals	5·0
Swinging Conveyor (balanced)	8·0
„ „ (unbalanced)	8·75
Push-Plate Conveyor	12·8
Worm Conveyor	18·38
Tubular Worm Conveyor	25·0

The difficulty of obtaining reliable data concerning power consumed by conveyors has been considerable, but the figures given above may be relied upon for practical purposes.

Rate of Travel,—The following are the comparative rates of travel in the different kinds of conveyor:—

	Average Speed. Feet per Minute.
Band Conveyor between 250 feet and 600 feet per minute	425
Push-plate „ 60 „ „ 180 „ „ „	120
Cable „ 100 „ „ 120 „ „ „	110
Travelling Trough „ 60 „ „ 120 „ „ „	90
Swinging „ 40 „ „ 70 „ „ „	55
Worm „ 40 „ „ 60 „ „ „	50

Wear and Tear of Elevating and Conveying Machinery.—A comparison of the cost of maintenance of elevating and conveying plant of different kinds is given in the Table on p. 95, which with the exception of the last item, was compiled by the late Mr.

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FIRST COST AND COST OF REPAIRS, ETC., OF ELEVATORS AND CONVEYORS.

Apparatus.	First Cost.		Tons of Material Transported.	Distance of Traverse.	Costs for Repairs and Renewals.			Description of Material conveyed.
	Total.	Per Lineal Foot.			Total.	Per Ton.	Per Ton for 100 Feet of Traverse.	
	£	£ s. d.		Feet.	£ s. d.	d.	d.	
Elevator	1,554	4 4 0	335,237	74	86 1 6	0·061	0·082	Coal.
„	819	6 6 0	178,541	58 & 72	679 6 8	0·913	1·405	Partially hot coke.
„	428	5 7 0	37,685	40	7 4 0	0·046	0·115	Oxide of iron and lime.
Push-plate conveyor	296	2 9 4	149,350	30	70 6 0	0·113	0·377	Coal.
„ „	1,486	5 3 11	29,769	90 90 106	110 11 3	0·891	0·988	Hot coke.
Plate-belt conveyor .	2,026	3 12 6	149,350	125 125 125 125 60	2,311 0 0	3·714	2·070	„ „
Canvas band . . .	443	4 10 0	(say) 10,000	98	40 0 0	(say) 1·00	(say) 1·00	Small coke and breeze.
Band conveyor . .	296	2 9 4	149,350	30	70 6 0	0·113	0·377	Coal.
„ „ . .	172	1 11 3	2,180	110	42 1 1	4·63	4·21	Sulphate of ammonia.
Swinging conveyor .	1,767	1 0 6	250,000	21 conveyors. Total length 1,722 feet	15 0 0	0·114	0·0003	Coal.

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W. R. Chester, M. Inst. C.E., of Nottingham, who, as Engineer to the Nottingham Gasworks, tabulated this valuable information from machinery under his personal supervision. The last item in the Table was obtained from the Engineer of the gasworks at Zürich, where a number of swinging conveyors have been at work for more than 4 years.

III. Combined Elevators and Conveyors.

There are only two varieties to be mentioned under this heading, the travelling- or tilting-bucket conveyor, and the pneumatic conveyor.

The former is not unlike an elevator, in that it consists of two endless chains or ropes held apart at a fixed distance by suitable bars, which are fitted with small rollers at each end. Every link, or sometimes every second link, carries a bucket; so that the whole is an endless and unbroken chain of buckets, which, however, are not fixed like elevator-buckets, but are movable and suspended from a point above their centre of gravity (*Fig. 33*). When the conveyor is at work, the buckets hang always in an upright position, whether they are travelling horizontally or vertically. Each bucket carries its load to the point where delivery is required; and here it is met by some adjustable device which tilts it and thus empties the contents.

The travelling-bucket conveyor enjoys great popularity, especially in America, and its details have been very carefully designed. A very complete form of it is used where coal has to be conveyed to overhead bunkers over boilers. Instead of using a separate conveyor to bring the coal from the railway sidings, and employing an elevator to raise it to the level of the bunkers, afterwards again using a conveyor to distribute it from the elevator to the different compartments of the bunkers, the three operations are performed by a travelling-bucket conveyor; and sometimes the returning empty buckets are used to convey the ashes away from under the boilers.

The driving-gear is usually unlike that of the ordinary elevator or chain-driven conveyor, being independent of the conveyor itself. It actuates the conveyor by a series of pawls attached to a wheel, each of which pushes the conveyor forward, link by link (*Fig. 33*). Or sometimes there is a wheel, with suitable projections which are of the same pitch as the buckets, and gear, as it were, into a portion of the continuous chain of buckets.

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The device for loading each of the buckets without spilling the

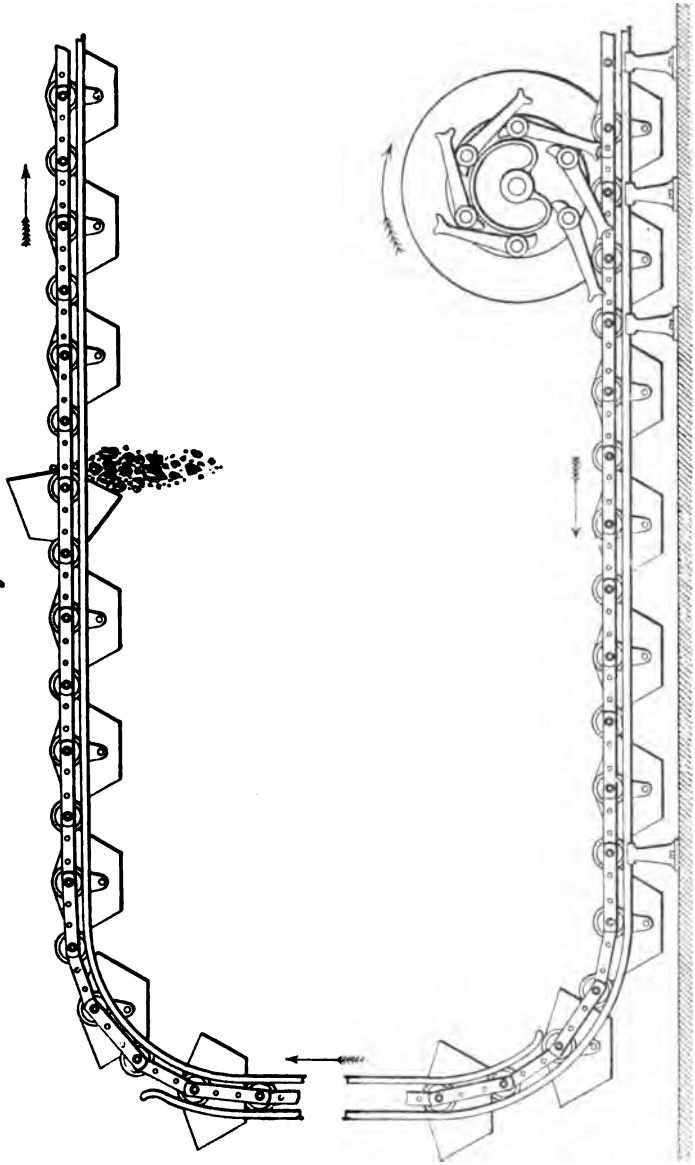

Fig. 83.

TRAVELLING-BUCKET ELEVATOR AND CONVEYOR.

material is a matter of great importance; and the object is effected

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in two ways. Either the buckets are filled by a series of small

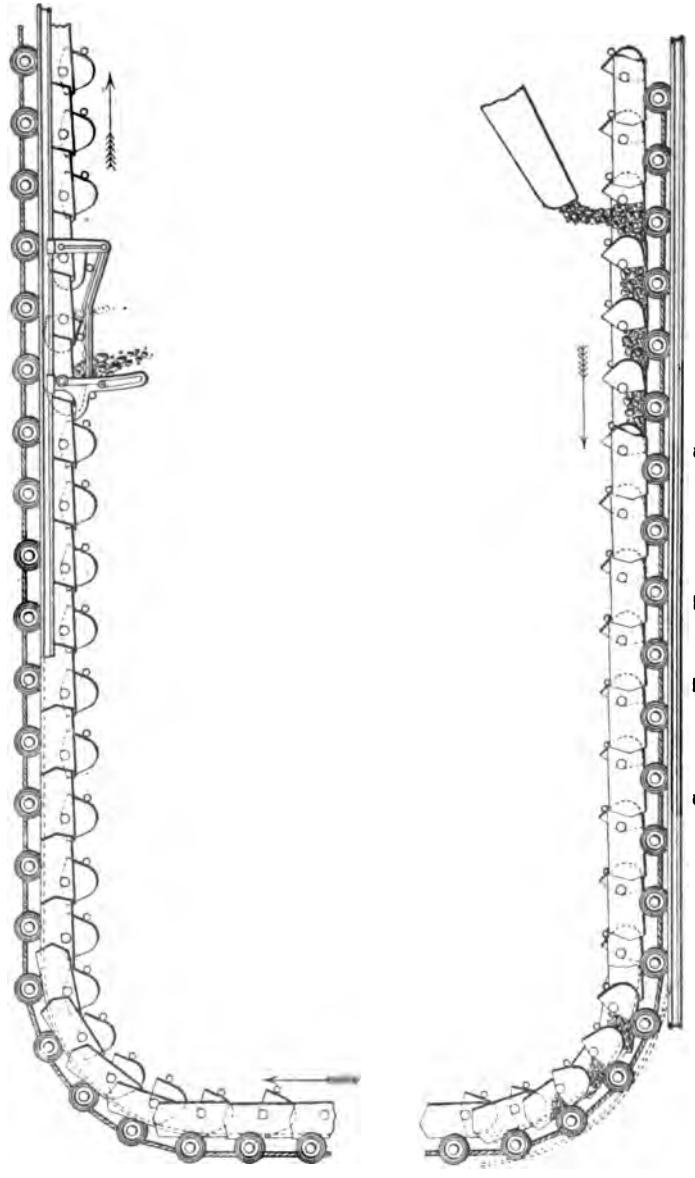

Fig. 31. CONTINUOUS-TROUGH ELEVATOR AND CONVEYOR.

funnels, which form a small endless chain in themselves, and are made to revolve over the buckets; or else the conveyor itself

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consists of an endless trough, similar to a continuous-trough conveyor, in which the buckets are suspended. In the latter plan, when the conveyor runs horizontally the endless trough receives the feed; but as soon as the ascent begins, each short length of trough empties itself into its bucket, so that, when ascending, the buckets are separately suspended from their sockets in the movable trough, which runs empty alongside (*Fig. 34*).

As the speed of travel of these conveyors is low, the necessary capacity is obtained by having the buckets of a size corresponding with the load to be conveyed. The rate of travel is generally between 15 feet and 25 feet per minute; and the power required depends to a large extent on how much of the total length is used for elevating. The advantages are that the material conveyed is not injured in the least, and it can be fed to the conveyor and withdrawn at any point. Such a conveyor requires little driving-power, and one main drive is sufficient for a whole installation. The disadvantages are that, if one portion of the apparatus breaks down, the whole is at a standstill; whereas, if different appliances are used for elevating and for conveying, part of the machinery can always be at work. Further, there are a large number of journals to be lubricated

Pneumatic Elevator.—The second appliance coming under the head of combined elevator and conveyor is the pneumatic elevator. Though earlier used in America, it did not, so far as the Author knows, pass beyond the experimental stage until Mr. F. E. Duckham, M. Inst. C.E., designed the apparatus which has been in use since 1895 at the Millwall Docks, and in docks of other ports. It is so different from all other machines for the purpose of conveying, that it deserves special mention.[1] The apparatus consists essentially of an air-tight tank, into which is led a pipe coming from the bulk of material (generally grain) to be conveyed. By means of a second pipe connected to an exhauster, air is drawn off from the tank at the top; and the air from the grain-store, or ship's hold, which comes up to fill its place, carries with it—practically in a floating condition—the grain, which is deposited in the hopper bottom of the tank. It is then removed from the tank without destroying the partial vacuum, by an ingenious arrangement illustrated in *Fig. 35*. Here the pipe A leads from the grain-store into the tank B, and the pipe C from the tank to the exhauster. Beneath the hopper-bottom D of the tank is a receptacle divided into two compartments, H and H_1, which oscillates on its axis, so that H and H_1 receive the grain

[1] See also Minutes of Proceedings Inst. C.E., vol. cxxv. p. 296.

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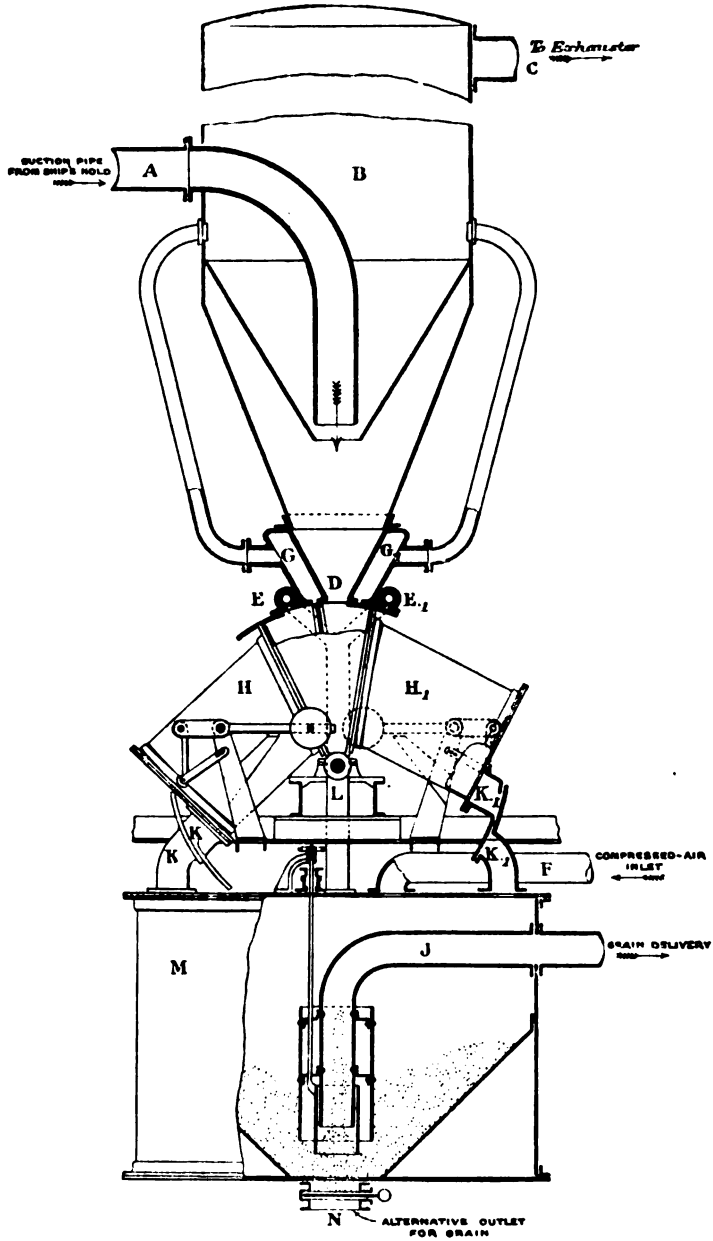
Fig. 35.



PNEUMATIC ELEVATOR AND CONVEYOR FOR GRAIN.

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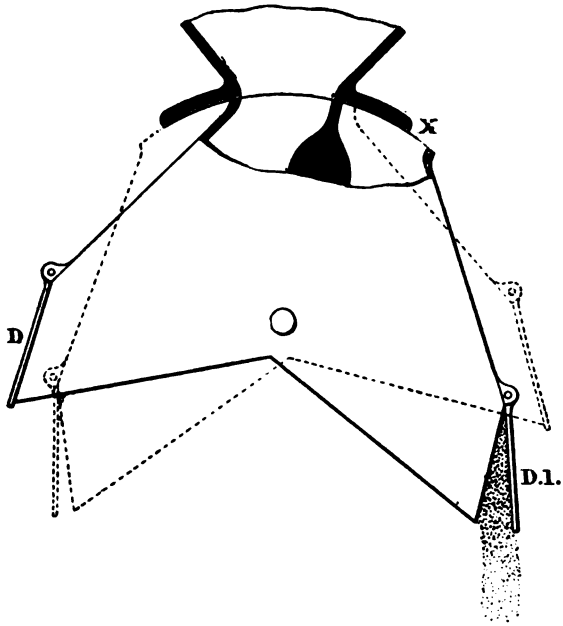
alternately through an aperture at the top. The outlets K and K_1 are opened and closed by the same oscillating movement: so that when H_1 is receiving its load its outlet K_1 is closed; and the inlet to H is closed while it is discharging its load through K, which is open.

In *Fig. 35* is shown not only the delivery of grain by suction, but also its further discharge into granaries by air-pressure. Into the tank M, which receives the grain through the pipes K and K_1 alternately, compressed air is forced through pipe F, and pipe J carries the air and grain away to its destination.

Fig. 36.



PNEUMATIC ELEVATOR FOR GRAIN: OSCILLATING DISCHARGE-BOX.

The grain can also be withdrawn at N. The ports $G G_1$ and $E E_1$ are for the purpose of establishing communication, and thus equalizing the pressure, between B and H or H_1 just before the filling operation takes place, and between M and H or H_1 just before the emptying begins. If the grain leaving the oscillating discharge-box can reach its destination by gravity, the apparatus can be much simplified, as illustrated in *Fig. 36*, where the rocking receptacle is shown in its two extreme positions, one in full and the other in dotted lines. The

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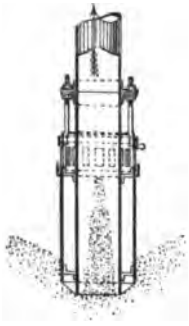
outlets from the two compartments are ordinary flap-doors, D and D_1, with india-rubber linings. During loading they are held closed by the vacuum within. When one compartment is full, the whole receptacle rocks over into the other position, and in so doing first shuts off the feed and with it the vacuum, and then opens the port at X which communicates with the outer atmosphere; whereupon the valve opens and allows the load to run out. The partition between the two compartments is weighted in order to assist the grain in throwing the apparatus over.

Fig. 37 shows the construction of the suction-nozzle. The suction-pipe which connects this nozzle with the vacuum-chamber, is about 6 inches in diameter, and consists of plain wrought-iron piping for the straight lengths and flexible hose for the bends. The hose is armour-plated inside, and is covered with india-rubber, with insertion to keep it air-tight. The delivery-nozzle, which deposits the grain in the granary or other destination, is illustrated in *Fig. 38*. It consists of an iron pipe about two or three times the diameter of the supply-pipe, and of a length five to ten times the diameter of the latter. The pipe J, which leads from tank M (*Fig. 35*), is connected to the delivery-nozzle, and as soon as the air carrying the grain expands in the wider nozzle, the velocity of the grain is reduced, and it runs out of the nozzle in a uniform stream.

Fig. 37.



PNEUMATIC ELEVATOR: SUCTION NOZZLE.

A partial vacuum of about 10 inches of mercury is necessary for working the pneumatic conveyor. With this vacuum the grain travels in the suction pipe at the rate of 30 feet to 50 feet per second; so that one pipe would convey 30 tons to 40 tons of grain per hour. As one vacuum tank is fed by at least two pipes, its capacity is 50 tons to 60 tons per hour.

Fig. 38.

PNEUMATIC ELEVATOR: DELIVERY NOZZLE.

The power required for working such a conveyor is about 3 HP. per ton of grain conveyed per hour. This is rather high; but as the whole appliance is so practical, and therefore requires a minimum of labour, it is undoubtedly the best where

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such large quantities as cargoes of grain have to be handled in the shortest possible time.

Timber Conveyor.—One other conveyor, which does not come under any of the foregoing headings of this Paper, is the Bolinder timber-conveyor at work at the Millwall Docks for conveying boards. It is somewhat on the principle of the band conveyor, but in the latter the band is driven and causes the supporting rollers to revolve; while in the Bolinder conveyor the rollers are made to revolve, and thereby propel the boards placed on them. *Fig. 39* shows a transverse section through the conveyor on its supporting structure, with the elevators which lift the boards and deliver them upon it. *Figs. 40* show another cross section, and a longitudinal elevation of the conveyor. The rollers A are of cast iron and are 10 inches in diameter by 2 feet 6 inches long. They are spaced 5 feet apart, and are driven by a small steel shaft, about 1 inch in diameter, and running the whole length of the conveyor, to which each roller is geared by a pair of bevel-wheels reducing the speed about 3 : 1. The rollers project slightly through the bottom of a trough, in which the boards travel at the rate of 150 feet to 200 feet per minute, the rollers themselves making 60 revolutions to 80 revolutions per minute. The boards to be conveyed must be more than 10 feet long, so as to rest always on not less than two rollers.

The most remarkable feature about this simple and effective conveyor is that it can be built in curves as well as in straight lines. The one at the Millwall Docks describes several curves having radii of 170 feet to 190 feet. The steel driving-shaft is sprung into the curves, and appears to work well therein, although no doubt it consumes more driving-power there than in the straight lengths. The driving-power is supplied by a separate electromotor of 5 HP. for every 500 feet of length, the motor itself being placed half way. The rollers of successive lengths of 500 feet are speeded so that the rate of travel of the timber increases by 20 feet per minute in each length, in order to avoid collision at the junctions.

The importance of handling materials mechanically in large factories and power-stations has been recognized widely; and practically no power-station or gasworks of any note has been built of late years without adequate provision being made for this purpose, and either wholly carried out or reserved in part for future extension. Moreover, in work of a temporary nature, such as excavations for docks and other large contractor's works, elevators and conveyors might be employed to great advantage as an

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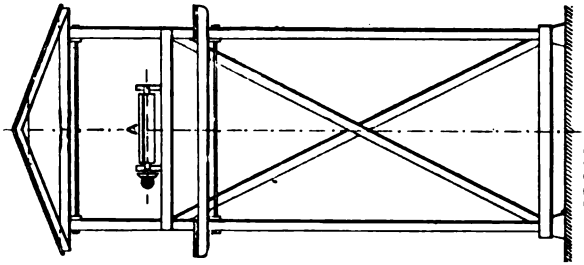
auxiliary to grabs, steam-navvies and power-shovels. The swing-



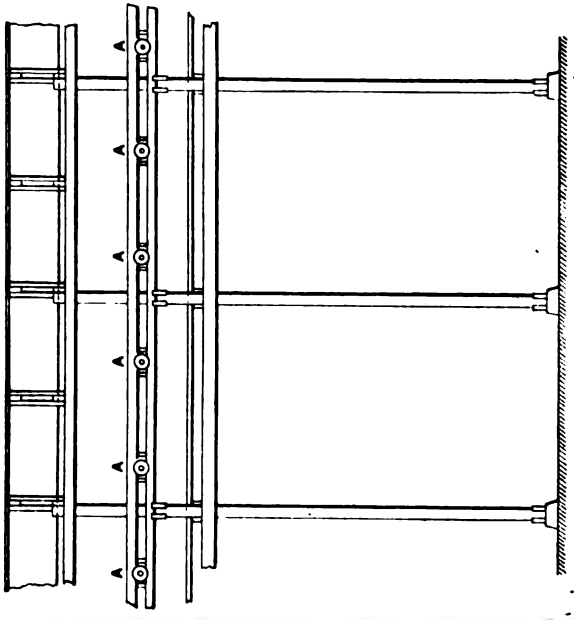


Fig. 40. Bollinder Timber Conveyor.

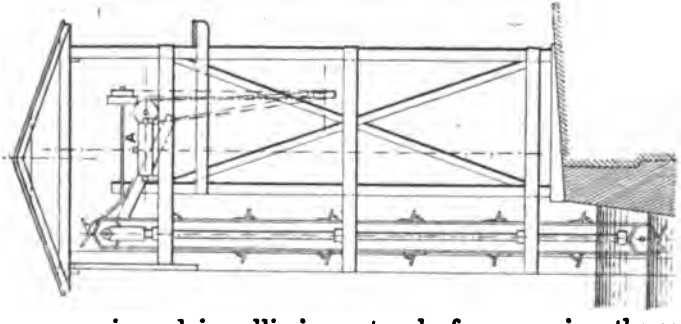


Fig. 39.

ing conveyor is used in collieries, not only for conveying the coal

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from the pit-mouth to the railway trucks, but also for sifting the coal at the same time into three or four sizes, and for delivering each size to a separate truck. The same plan might be adopted with equal advantage where gravelly soil has to be excavated. The conveyor would remove the spoil to its final or intermediate destination, and at the same time would deposit at different points sand and various sizes of gravel, etc., suitable for concrete.

It is not claimed that all the existing types of elevators and conveyors have here been mentioned. Those which have been described are such as have come within the scope of the Author's own experience, which has led him to believe that the automatic handling of all materials can be successfully carried out by one or other of the means enumerated.

The Paper is accompanied by twenty-six drawings, from which Plate 2 and the Figures in the text have been prepared.

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Discussion.

The President. The PRESIDENT, in proposing a vote of thanks to the Author for his interesting Paper, remarked that the subject was one of growing importance. As the cost of labour and the difficulties of dealing with it increased, it became necessary to have recourse in larger measure to labour-saving appliances. As the Author admitted, the Paper did not mention all the interesting elevators and conveyors which were in use. The appliances for dealing with timber, for instance, were almost worthy of a Paper to themselves. In Norway, transporters had long been used for taking timber from the water to the mill. There were endless chains running on rollers in a trough and on an incline which passed just below the water-line, and the logs were floated over the chains, which were furnished with vertical spikes. When a log touched the spikes, its weight ensured a hold, and it was thus hauled out of the water and often transported a long distance to the mill. There were other appliances for stacking and transporting sawn timber, and appliances for getting rid of the saw-dust from the mill. The old plan had been a trough wherein ran an endless chain drawing small boards, which scraped up the saw-dust. The plan now used was to fix below each machine in the mill a hopper connected by a pipe with the chamber of an exhaust fan, which drew the whole of the saw-dust from the mill and conveyed it through the pipe to any convenient place. There it was delivered into that beautiful contrivance called a "cyclone," by which every particle of dust was caused to settle. In addition to appliances for timber, there were appliances for dealing with dredged material, such as the floating tubes used at the Amsterdam Canal, and various other contrivances used at the Suez Canal and the Manchester Ship Canal. He merely mentioned those to show that, numerous and interesting as were the appliances which had been dealt with in the Paper, there were many others which were also worthy of consideration.

The Author. The AUTHOR exhibited a number of lantern-slides illustrating various appliances for the mechanical handling of materials, including the Phillip lighter (*Figs. 41*) for carrying grain and for discharging it, at the rate of 120 tons per hour, to a barge elevator.

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Between the double keelson ran a band conveyor 28 inches wide, which delivered into the small fixed elevator placed in the stern

The Author.

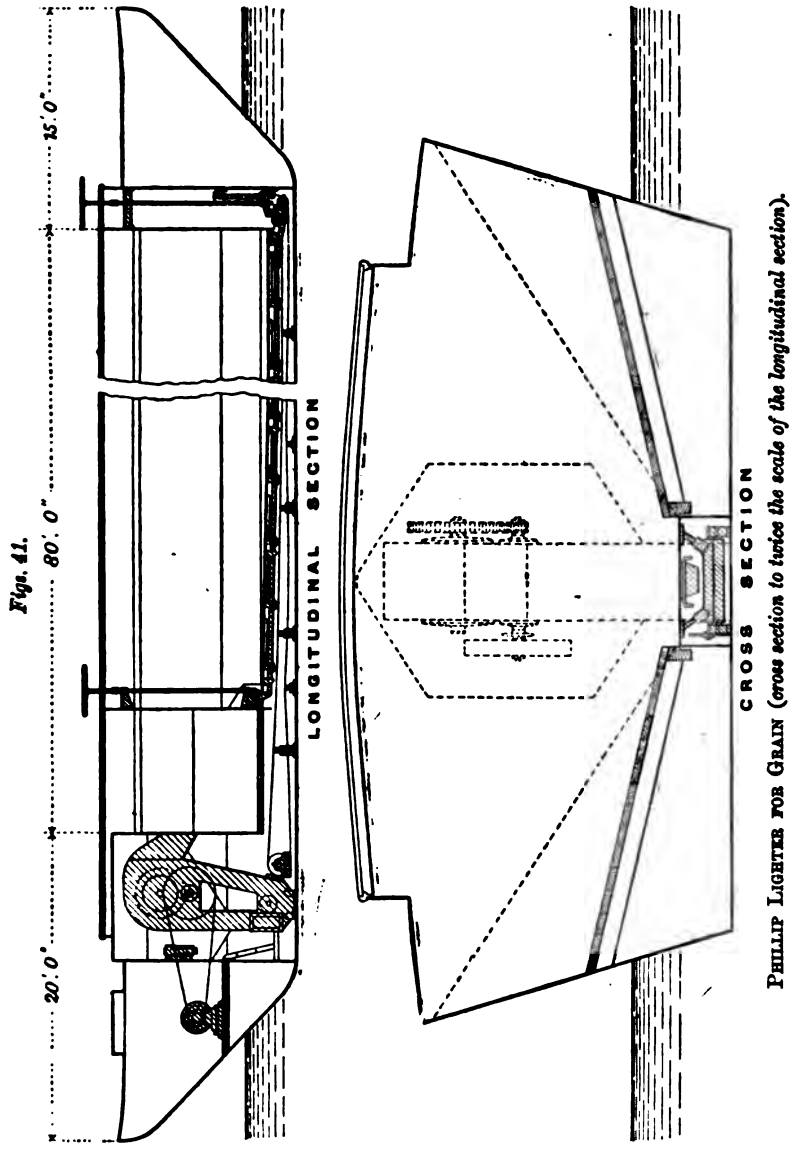

Fig. 41.

PHILLIP LIGHTER FOR GRAIN (*cross section to twice the scale of the longitudinal section*).

of the lighter. Both were driven by electromotors of 6½ B.HP. The bottom of the barge was hoppered to save trimming. These

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The Author. lighters carried 200 tons of grain, and a fleet of twenty-six brought grain from Tilbury to the Port of London, for the London Grain Elevator Company. He also described the appliances for conveying coke which were in use at the Margate gasworks. An inclined bucket elevator took the coke from the retorts immediately after it was quenched, and delivered it through a push-plate conveyor on to a coke-breaker. The coke next went through a revolving screen, which removed the breeze, and then passed along another push-plate conveyor, either into a series of coke hoppers, for delivery into carts, or to a swinging conveyor which deposited it in the yard. This latter conveyor was 130 feet long and 16 inches wide, and conveyed about 10 tons per hour. It was fitted with intermediate outlets with slides, so that the coke could be delivered at any point.

Mr. Patchell. Mr. W. H. PATCHELL considered that the members were indebted to the Author for having made an addition to the scanty literature of conveying-machinery. As users, if engineers had not had practical experience of their own, they were almost entirely in the hands of the manufacturers; and then the danger was the liability to take the lowest-priced plant, with the result that the wear and tear was found to be extremely heavy. The speeds and other particulars which the Author had given would be of considerable assistance to users; and they would be even more so if the engineer of the Nottingham gasworks could supplement the Table on p. 95 with a few particulars of the sizes of the machinery and the speeds at which it ran. He had had an unfortunate experience with an elevator of the kind illustrated in *Fig. 4*, with a boot at the bottom, and tightening-gear which gave a variable distance between the bottom of the bucket and the boot. When used for ashes or coal, such a contrivance was apt to become clogged; and it would be better to make the clearance at the bottom as small as possible, which meant that the tightening-gear must be at the top, instead of at the bottom. With grain that difficulty would not occur; but with ashes and clinker a sodden mass accumulated in the bottom which seriously increased the wear and tear on the buckets and chains. The belt conveyor was one of the most fascinating of those which the Author had described. A long belt conveyor at work was a pretty sight; but, when desiring to use a belt conveyor about 500 feet long for delivering at different points along its length, he had considered the arrangement of a throw-off carriage with "jockey" pulleys, and had fought shy of it. For simple end delivery, for which they

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were frequently used, belt conveyors ran admirably. In connection with them the question of cost again arose. He had seen a low-priced conveyor in which the belt had given endless trouble by refusing to run straight without a number of guide-pulleys at the sides; and, in addition to pulleys for maintaining the dish of the belt, such as were shown in *Fig. 26*, little pulleys had had to be put on at right angles to those, in order to keep the belt in position. Side by side with that conveyor he had seen another higher-priced belt running practically without guide-pulleys. Those facts showed the necessity for care in the selection of a belt-conveyor. He had tried the trough or tray conveyor, and it was surprising what a difference there was in the wear and tear when the rollers which took the weight of the returning trough—supposing the trough to be returning underneath—engaged on the edge instead of on the flat of the trough or tray. If they were on the edge, the grit from the clinker soon cut a groove through the rollers, like the cutting of an emery-wheel. The conveyor shown in *Figs. 33* and *34* was known to most engineers as the Hunt conveyor, having been introduced originally into England by an American of that name. It was a useful and convenient conveyor if the engineer did not object to putting all his eggs in one basket; the great objection to it was, as the Author said, that if a breakdown occurred it stopped the work completely. The introducers of the contrivance into England had recommended it—and in some cases had used it—to bring the coal in and the ashes out. He thought that plan was open to criticism. It was impossible to get the ash-buckets clean after carrying wet ashes; and to use them in the way recommended seemed like getting the dustman to deliver bread. It would be useful if the Author would state what measures were generally taken for preventing choking in the ordinary form of bucket elevator. In the arrangement with large clearance at the bottom, some such steps must be taken. He had asked several contractors and manufacturers what they were doing in that respect, and at one time he had received a promise that he should be shown an excellent arrangement for preventing the choking. On going to the works he had found a boy sitting on the end of a cask, and holding a stick across the mouth of the boot! He thought manufacturers of conveyors ought to be able to give engineers something better than that.

Mr. Patchell.

Sir JOHN WOLFE BARRY, K.C.B., Past-President, asked whether the Author had devoted attention to the shipping of coal-cargoes in large ships, in which matter some arrangement of conveyors was

Sir John Wolfe Barry

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Sir John Wolfe Barry.

one of the crying wants of the day. The speed at which coal could be shipped depended entirely upon manual trimming; and although special vessels were built, with a large number of hatchways, so as to diminish as much as possible the handling of the coal by men, yet the bulk of the coal was shipped in vessels which were not specially built for the traffic. In such vessels the handling of the coal was a source of expense and loss of time; and if any machinery could be devised which would be suitable to the different kinds of vessels used, and would serve to convey the coal rapidly from the hatchways where it was deposited to the different places between decks, it would no doubt meet an important want. In view of the many million tons of coal shipped every year from England, there was a wide field for any really well-devised scheme for such trimming of coal in vessels; and he would direct the attention of those engineers who had already exercised so much ingenuity in such matters, to that requirement of the present day. With regard to other modes of conveying materials, not touched upon in the Paper, he had one now at work under his direction in Scotland, for dealing with dredged material from a large dock. Instead of excavating in the dry and using tramways or similar appliances for transporting the spoil, the contractor was dredging out almost the whole of the excavation under water, after the construction of the walls; the material was delivered into barges, and from the barges it was transmitted 1,000 yards or more, through large pipes, by means of a centrifugal pump working under pressure. The plan seemed to be highly successful and profitable to the contractor. It was a mode of constructing docks which ought not to be neglected; because, as those who had to deal with such work knew, the great risk which had to be run in constructing a dock occurred while the excavation was being made, and before the water was let in. That mode of dredging enabled the water to be let in immediately after the walls had been built in trenches; and the walls thus had the support of the water while the excavation was being made. The transport was remarkably cheap, and the only thing necessary was that experience which would indicate the amount of power required for breaking up and adapting the material, so that it would pass readily through the centrifugal pumps under pressure. He commended the arrangement to other engineers. One thing about it he did not like, namely, to find that the whole of the apparatus came from Holland, and that British engineers had not been sufficiently ingenious to make it a more regular system of work. Engineers often pumped material through pipes by centrifugal pumps; but

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what he had referred to was a systematic arrangement which had been carefully worked out by Dutch engineers, who came over to England and undertook the work there at lower prices than Englishmen could touch. Sir John Wolfe Barry.

Mr. J. N. SHOOLBRED described briefly an installation which performed work somewhat analogous to the loading or unloading of ships, to which Sir John Wolfe Barry had referred. The Doncaster power-station had, on one side, a large Yorkshire canal which could accommodate barges of 200 tons burden, and on the other side a line of rails. It was therefore particularly well situated for supplying the needs of the boilers. In the boiler-house there was a conveyor with a large bucket, by means of which ½ ton of coal at a time could be dipped from the barge and conveyed to any part of the boiler-house, which contained a range of ten Lancashire boilers. By a similar arrangement, coal might be loaded from a lighter alongside a vessel. In the Doncaster power-station, the arrangement was driven electrically, and was controlled by one man, who could see the whole operation. The installation had worked for at least 2 years, and, as far as he could remember, 150 tons of coal were dealt with satisfactorily in a comparatively short time. Mr. Shoolbred.

Mr. H. B. MOLESWORTH remarked that one form of conveyor which he had seen in the United States was not mentioned in the Paper; it was used in connection with blast-furnaces, and saved a great deal of labour. The conveyor consisted of a series of trays with sloping sides, which ran under a ladle; the molten iron was run into the trays, which ran slowly for about 200 feet under jets of water. The pigs were then discharged into a railway wagon, having been cooled in their passage from the furnace. On p. 62 the Author said, "In order to effect perfect discharge, the centrifugal force must be sufficient to overcome the gravity of the material: so that for a specifically heavy material it is necessary to have a greater centrifugal force, *i.e.*, higher speed of elevator, than for a specifically lighter material." This he could not quite follow, and he would be glad if the Author would explain it. The centrifugal force, it appeared to him, was a function of the mass, and not of the density of the body; and, *in vacuo*, bodies travelling with equal circumferential speed would describe similar paths, irrespective of their densities. If the friction of the air were taken into account, a light body, no doubt, would not throw as far as a heavy body. He therefore thought the result would be that for a specifically heavy material a slightly lower speed, if anything, would be required, rather than a higher speed, as the Mr. Molesworth.

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Mr. Molesworth. Author seemed to suggest. The means for handling material were often ill adapted to the end. A glaring instance of this was the use of the steam travelling jib-crane in workshops. That crane always reminded him of a boy's knife with twenty blades, etc., which was intended for every purpose. In attempting to open the gimlet, the boy generally broke his nails; and when he tried to make a hole with the gimlet, one of the blades shut on his fingers. The steam-cranes in workshops were like that knife. The average weight of a 3-ton steam-crane, for instance, was about 35 tons, and when under a load it was, to say the least, in a state of unstable equilibrium. The load was frequently concentrated almost entirely on one wheel, and, as could be imagined, a 35-ton wheel-load was destructive to the permanent way. As soon as the newness of the gear had worn off, the crane was nearly always breaking down and needing repair; it covered a large space in moving about, and spent half its time in going back for a fresh load, or carrying a bucketful of ashes.

Mr. Brown. Mr. ANDREW BROWN remarked that, with reference more particularly to coal-elevators and conveyors, he took exception to the Author's remarks as to the necessity of having coal-elevators inclined, and also as to less power being required for driving inclined elevators than vertical elevators. He could not see why, in lifting vertically a load suspended on a lubricated bearing, more power should be required than in performing the same work with an inclined elevator, which must of course be longer and also heavier, on account of the longer chain and the larger number of buckets attached to it. Having regard to the friction at the sides on which the buckets bore, an inclined elevator must require more power than a vertical elevator, for lifting the same quantity of coal through the same height in a given time. With regard to throwing off at the head, no doubt at first sight the inclined elevator was in a better position for throwing into the shoot; but he had found no difficulty whatever in arranging the throw-off of vertical elevators so as to be perfectly clear. The advantage to be reaped in either case was often a question of convenience. In many gasworks and boiler-ranges, the coal was delivered at the side of the building; and then it became necessary, if elevating was to be done, to throw the coal over at an angle, in order to get it into the continuous conveyor which was to deposit it at the various retorts or boilers. If convenience was taken into consideration, he agreed that under these circumstances the inclined conveyor should be used; but he had no hesitation in saying that where coal could be delivered at the

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end of a building, and could be thrown directly into the longitudinal conveyor, the vertical elevator was the more easily adapted, because it could be fixed close against the wall, and heavy structures, such as were necessary for an inclined elevator, were not required. With regard to the speed of elevators, it was important that the speed required at the point of throw-off should be known exactly. In *Fig. 4*, the bucket was suspended in the centre-line of the pitch-chain, and as it passed over the sprocket its speed was the same as that of the chain. But in *Fig. 1* the bucket was attached to the outside of the chain, and when it arrived at the sprocket-wheel the mean radius of its path was increased by half the width of the bucket. Thus, if the buckets were 6 inches wide, and the sprocket-wheel 2 feet in diameter, the mean radius of the path of the buckets would be $12 + \frac{6}{2} = 15$ inches; so that the speed at which the contents were thrown off at the top was here 25 per cent. higher than with such an elevator as was shown in *Fig. 4*, having a pulley of the same diameter, namely 2 feet. The vertical elevator was therefore capable of throwing the coal clear of the preceding bucket, and into the shoot. If the shoot, instead of being so close to the top as it was shown in the diagram, was extended horizontally and then inclined, the coal would be thrown off at the top almost horizontally, and would drop down the shoot. In calculating the speed of chain required to deliver a certain quantity of coal, it must be remembered that if the bucket was suspended on the outside of the chain, as shown in *Fig. 1*, it must be a little larger, and the speed of the chain a little less. With regard to the push-plate conveyors mentioned in the Paper, he did not think all had been said in their favour that might have been said. Such examples as were illustrated in *Figs. 16* and *17* were not altogether suitable for feeding hoppers connected with the stokers of boilers, or the hoppers of gas-retorts; because the return chain ran at the bottom of the conveyor-trough, instead of along the top. Apart from that, the section of trough shown in *Fig. 16* was so shallow that it would scarcely hold sufficient coal. In *Fig. 17* an arrangement was shown which the Author advocated, because it allowed the chain to be as nearly as possible in the centre of the push-plate. He had seen such an arrangement at work; and whenever it was loaded to its full extent the coal jumped over the top of the push-plate, and the arrangement was not effective. Again, the rubbing part shown in the centre was always covered with coal, and did not at all relieve the chain in its course through the trough. In a conveyor erected by him about 7 years ago, he had

Mr. Brown.

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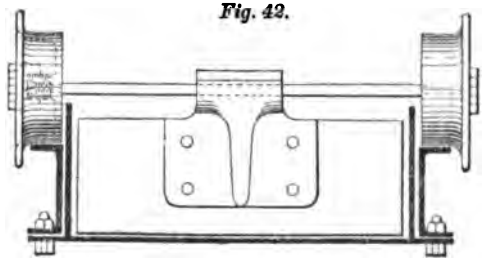
Mr. Brown. adopted the arrangement shown in *Fig. 42*. The trough in which the push-plate ran was flat-bottomed and 12 inches wide, the sides being 6 inches deep. The runners ran upon channel bars 4 inches deep. The axle passed just above the top of the trough sides, the intention being that the wheels should be as low as possible, while a large area was obtained for the coal to travel in. On the boss of each pulley a grease-cap was screwed, which forced the grease on to the axle, and formed a bearing into which coal-dust could not penetrate. The conveyor delivered 20 tons of coal per hour: the pitch of the plates was 2 feet and the travel 150 feet per minute: the total length of the conveyor was 120 feet. It had now been working for 7 years, and the chain had never been off the sprocket-wheels. The amount of wear and tear was very small, and the conveyor was so free from repairing-charges that he thought it compared favourably with the figures given in the Paper. A similar conveyor, 18 inches wide, with the

Fig. 42.



push-plates 21 inches apart, delivered 60 tons per hour. It was 350 feet long, travelled at 150 feet per minute, and had been working for 18 months without any failure. The two conveyors in question had been designed for gasworks, with the intention that they should not work continuously. They worked for 5 hours out of the 24, the one delivering 100 tons and the other 300 tons in that time. The intention was that, when a fresh shift of men came on first thing in the morning, they would immediately fill the hoppers for the retorts; and in the afternoon, before they left, they would put in the supply for the night shift, so that the machines were not worked during the night. In the Table on p. 95, a conveyor which transported coal 30 feet was mentioned as costing £2 9*s.* 4*d.* per lineal foot, which meant under £70 for the total cost. But the first cost of that conveyor was given as £296; and he would like to know why the extra £226 had been added. Further, the cost of repairs to the same conveyor was stated at £70 6*s.* He would like

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to know what period of years was covered by that expenditure, because it was difficult to understand how the cost of repairs came to be equal to the first cost of the conveyor. Possibly the £226 added in the first instance represented the cost of steam-engines, screens, crushers, and other accessories in connection with the plant. He thought the arrangement illustrated in Plate 2 courted disaster. In the first place, the hopper was shown as standing immediately above the coal-breaker, and there was no indication of any device for intercepting foreign material, such as stone sets, railway brakes, broken wheels, and other things which were found in railway wagons. Unless such things were intercepted, speedy destruction of the coal-crusher resulted. Another essential point was that, before passing into the crusher, the coal should be passed over a grid, which would allow the small coal to drop down to the elevator-boot, and not pass through the crusher at all. The addition of these two details would render more effective the arrangements shown in the diagram. Mr. Brown.

Mr. S. W. PORTER remarked that when the tightening-gear of an elevator for such materials as coal had a range inside the boot at the bottom, the distance between the lip of the bucket and the curve of the bottom plate of the elevator varied. In a good elevator that distance should always be about 1 inch. With a tightening-gear of 7 inches or 8 inches range, a block might be caused by large pieces getting in when the buckets were some distance from the bottom. In order to remedy that, elevators were designed with tightening-gear at the head. They worked satisfactorily until it became necessary to tighten the chains, which had to be done by lifting the sprocket-wheels: the whole of the gear which drove the elevator had then to be adjusted, and probably the positions of the delivery-shoot and the elevator-head had to be altered. He had had experience lately of such elevators, and had found that it was a good plan to have the tightening-gear at the bottom, but, instead of having the wheels rising and falling in the boot, to have the boot itself moving up and down; that was, the buckets at the lip were 1 inch off the bottom plate, the legs were supported by means of brackets from the floor, and the boot was arranged to slide up and down between the brackets. The tension-screws thus kept the chain tight, without altering the distance between the lip of the bucket and the curve of the boot. The buckets of the elevator were continuous. In most coal-elevators the dredging action was a cause of serious wear and tear and waste of power. His practice was to feed the material into the leg about 2 feet above Mr. Porter.

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Mr. Porter. the bottom of the elevator. The buckets were made almost to fit the leg for this distance. The material was fed in gently from the feed-shoot and was deposited straight into the buckets, nothing being allowed to go past to the boot. The running of the bands in band conveyors depended chiefly on their quality. Bands varied considerably, and inferior bands always did run a little erratically; but a band of the best quality, such as was now made with a breaking-stress of 400 lbs. per ply per inch width, usually ran true; because, although a band of that quality stretched to some extent, it did so equally, and the tightening-gear could be arranged to take up the whole of the stretching of the belt, which, wherever possible, was endless. The Author advocated tightening-gear of the weight type, which was necessary when the throw-off was of the swivelling kind shown in *Fig. 23*. When the material had to flow past, it was necessary to have a throw-off of that description; but it was much better, where possible, to have a throw-off with the pulleys fixed, such as was shown in *Fig. 25*. The tightening-gear could then be made with tension-screws, which was by far the best method. With such gear there was a screw on each side; and instead of being pushed, as described in the Paper, the pulley was pulled, the screws being in tension; thus the tightening-gear could be made of almost any length. In practice he had found that about 4 per cent. of the length of the belt was sufficient allowance for the tightening-gear, if a belt of good quality was used. The true running of the belt depended also on the details, which were very important. The feed-hopper, for instance, must be so arranged that the grain or material came almost to rest on the back of the hopper, and then flowed down in a curve on to the band, in the line of travel, without any vertical drop. Further, the rollers must be balanced—an important detail which had not been mentioned. If the various points to which he had referred were attended to, no difficulty would be experienced from a belt not running true. Lubrication was of the utmost importance in conveying-machinery, on account of the large amount of grit and dust attending its working. He had found that thick grease, with automatic drop-pistons fitting into the caps of the bearings, gave the most satisfactory lubrication for the rollers.

Mr. Lockhart. Mr. WM. S. LOCKHART presumed that many of the conveyors described by the Author were for raising wheat. From an engineer's point of view, wheat seemed to have been specially created in order to be raised. Probably the boot with tightening-gear at the bottom was intended for wheat; it could never be cleared

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out, but with wheat the buckets could easily be got through. One plan of clearing a boot, which had not been mentioned, was to have one or two of the buckets of the elevator a little longer than the others, so that while most of the buckets worked fairly lightly the larger buckets cleaned up after them. If that was done, the tumbler at the bottom must work on a fixed point; therefore, it would not do to have the tightening-gear at the bottom. On the whole, where it was practicable, it was more convenient to have the tightening-gear at the top. He would like to know if such material as slurry or slimes could be conveyed with a vibrating-trough conveyor. There was nothing so difficult to move, even in a horizontal direction, as slime, unless it was run at a high speed. Even in a pipe it had a tendency to settle and block the pipe, though sometimes flat pipes could be used with advantage. It was so difficult to move slime in a horizontal direction that it was often necessary to hoist it up vertically and let it run down to its destination. The swinging conveyor might yield a solution of the difficulty, because the solid matter, which was exceedingly fine, would be kept constantly stirred while it was travelling. He presumed that such a conveyor could not be used to raise the material uphill, but that it should be inclined slightly downwards. He would like to know whether the conveyor had been used for damp gravel, which was a difficult material to handle. If so, at what angle, according to size, could the gravel be conveyed? Probably when sand was reached difficulties would arise. Mr. Lockhart.

Mr. A. R. TATTERSALL remarked that he had seen many of the conveyors which the Author described, at work on various materials; particularly the one advocated for coal, minerals and wet gravel. It had not been at work on an incline, but it had seemed to convey wet gravel successfully; how it would convey slimes he was not able to say. With regard to conveyors for loading ships with coal, he did not see why either the push-plate conveyor or the swinging conveyor might not be fixed to every coal-carrying ship, and serve to load the coal without much expense for trimming. He thought the swinging conveyor, in which the plates could be made with openings, might be applied so that ships could be loaded cheaply. With regard to the cost of maintenance, he had understood, in conversation with the late Mr. Chester, that he had placed the conveyors all on the same footing, namely, on the results of 1 year's work; and that his experience had been that the push-plate conveyor showed heavy wear and tear. At that time Mr. Chester had not made the acquaintance of the swinging conveyor, Mr. Tattersall.

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Mr. Tattersall. and had been unable to say how it would compare with the others. He would like to see the conveyor referred to by Mr. Brown as having conveyed coal for 7 years without ever having been off the sprocket-wheels: it would be a curiosity. The problem of conveying materials of all kinds in factories must necessarily force itself to the front as the difficulties connected with labour became recognized. In flour-milling it was rare to see the material handled at any stage; even the weighing, he believed, could now be done automatically.

Mr. Apjohn. Mr. J. H. APJOHN remarked that during the past 2 years he had had his attention specially called to the problem of loading coal mechanically. He had visited America twice in order to see what was being done there, and he had also inspected various conveyors at work in England. His experience was that the American systems were a great deal ahead. Nothing could be much better than the English practice of dumping the whole contents of a wagon into the ship, where it was practicable; but where it was not so, the American systems had great advantages. The conveyors described by the Author, which were apparently those in use in England, did not seem to be of large capacity, the speeds being low. In America much higher speeds were used, and thereby a much larger capacity was obtained. At Louisville, Nova Scotia, he had seen a ship loaded with 5,500 tons of small coal in 8 hours, by one belt conveyor giving off to the different hatches at intervals. It was usually worked at about 400 feet per minute, but when pressed the users did not hesitate to work it at speeds up to 700 feet per minute. He had been asked to draw up a scheme for loading coal for a large ship-owning company, and after carefully considering the matter he had decided in favour of an arrangement combining two kinds of conveyors—Brown hoist conveyors and Robins belts. The Brown hoist was necessary for putting the coal into stock, when the ship was not ready to receive it at once. The project he had submitted provided for stocking 50,000 tons of coal: it also provided for taking from stock and putting into the ship; or for putting into stock from the ship; or for loading direct from the wagons into the ship. The combined system provided for loading 400 tons per hour direct from wagons, and 170 tons from or into stock. For trimming in the ship there was an arrangement of scrapers. He had carefully considered the possibility of adapting a conveyor for trimming in the ship, but had found many difficulties. He had adopted a scraper which he had seen in operation in America, which worked very effectually, by electric power, and scraped the coal to the bulkhead.

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At Toledo on Lake Erie he had seen a ship being loaded by one Brown hoist conveyor. The coal was dumped from wagons containing 40 tons of coal, into buckets, each containing nearly 7 tons. The buckets were then lifted, and their contents placed in the ship. One conveyor travelling backwards and forwards served the four hatches of the ship in turn, and put in on an average 7 tons every 75 seconds, or about 300 tons per hour. Mr. Apjohn.

Mr. J. W. HELPS remarked that gas-engineers looked forward to the perfecting of some good plan of conveying with as much hopeful anxiety as did members of any other branch of the profession. One material had not been considered in the discussion—namely, coke. Of all the materials with which engineers had to deal, perhaps coke was the most difficult, especially hot coke. He had lately been looking carefully into the question of conveying it, had visited several works both on the Continent and in England, and had inspected many different conveyors. Finally, he had advised his directors to put down a push-plate conveyor. He had not had any extensive experience with it, but hitherto he had found it particularly satisfactory, except in one direction: unfortunately it was necessary to take the coke out at the sides of the retort-house and not at the ends; consequently the two conveyors which ran in front of the retorts had to discharge their coke on to a transverse conveyor, which had then to elevate the coke to the hoppers. Severe wear and tear took place at the point where the transverse conveyor left the horizontal and assumed an inclined position; and he had had to renew the wearing strips within 3 weeks of putting the machinery to work. One speaker had expressed the opinion that it was a mistake to deliver into a boot, and then allow the elevator to scrape the material from that boot. He entirely agreed with that opinion. He had visited a works some time ago where the cross conveyor delivered directly on to the buckets of the elevator, and he had been told that the amount of breakage to which the coke was subjected—which was an important matter—had been diminished to a large extent by doing away with the boot, and by adopting the system he had mentioned. He could not help thinking it was a step in the right direction to do away with the boot, which ground up the coke so much, and to deliver directly on to the elevator. Mr. Helps.

Mr. APJOHN stated that in America he had seen coke carried very successfully by belt conveyors. Mr. Apjohn.

Mr. F. E. DUCKHAM observed that, although it was advisable to use machinery wherever possible, the question whether it was Mr. Duckham.

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Mr. Duckham. advantageous or not to do so must always be considered. If a large capital outlay had to be made on a machine which was used only occasionally, that machine, however efficient, might not be worth the money expended on it. Moreover, for different materials different machines were necessary. Three or four different plans of conveying material were in use at the Millwall Docks. The oldest machine was used for conveying dredged material from a dredger to a point on land about 300 yards from the water-side. The dredged material was put into a tank, and air at a pressure of 20 lbs. to 25 lbs. per square inch was used for forcing it through pipes on to waste land. That process had been carried out successfully for the last 20 to 30 years. It was also necessary to convey timber from the water-side to a point 300 yards to 500 yards away from the quay. For that purpose conveyors like those to which the President had referred had been adopted. He had visited Norway and Sweden 3 years ago, for the purpose of inspecting such machinery, and seeing if it could be adopted at the Millwall Docks; and eventually he had come to the conclusion that it was admirably suited for the work. At Millwall the barges containing the deals were brought alongside the quay; at the quay-side there was a staging upon which were mounted four pairs of endless chains, which had dogs attached to them at intervals of about 6 feet. The men in the barge put a deal on to a pair of hooks, and each pair of travelling endless chains took up the deals one after the other, at the rate of about six per minute, to the top of the gantry, where they were tipped into a trough, in the bottom of which were a number of rollers revolving at about 120 revolutions per minute. On these rollers they were carried to the other end of the line or deposited intermediately, as desired. The motive power was electrical. Lastly, grain had to be lifted and conveyed. For lifting it out of ships, the pneumatic elevator was undoubtedly the most suitable arrangement. It not only lifted the grain fairly cheaply, but it had also the advantage that the grain could be collected from the different parts of the ship without the expense of trimming. Trimming into the hatchways cost 2*d.* to 4*d.* per ton, which amount was saved by carrying the suction-pipes of the machine to any part of the ship where the grain was, and so collecting it and bringing it to the elevator itself. But the pneumatic elevator was not suitable for every purpose. For lifting from the ground to the top of a granary it was not better than the ordinary grain-elevators described in the Paper. The Millwall Docks were now being equipped with a granary

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which would have a capacity of about 150,000 quarters, and a loading capacity of about 300 tons per hour. The work would be done by four pneumatic elevators taking the grain out of the ships, and by four horizontal band-conveyors taking it thence to the shore. When it was ashore, the lifting into the granary would be done with machinery of the ordinary kind, and the distributing by pipes which conducted the grain into the different floors. The granary had a floor-area of 7 acres, and, by diverting the flow of the grain, any part of the building could be reached. Mr. Duckham.

The AUTHOR, in reply, said that the tightening-gear was undoubtedly an important detail of an elevator. It was usually arranged at the bottom, because, if arranged at the top, the tightening of the chain or band generally upset the driving-band, unless this ran at right angles to the elevator. Where grain-elevators were concerned, it did not matter about the distance between the buckets and the elevator-well being variable. Where ashes, coal, or other material of varying size was raised, it was advisable to keep the space between the buckets and the well fixed, as in the elevator shown in *Fig. 4*; the elevator-well was designed to move up or down with the sprocket-wheel when the chain was adjusted, as mentioned by Mr. Porter. He did not think the elevator was likely to become choked at the bottom if the buckets were large enough to cope with the feed—making due allowance for the largest pieces—and if the elevator was properly fed. If it was fed from a large accumulation of material, a block was very likely to take place, or the feed might be stopped altogether, by the material forming an arch over the shoot; but in such a case the elevator should be fed by an oscillating feeding-shoot which deposited at each backward and forward stroke about as much material as the elevator would take; there would then be no choking. This was necessary only when the material came intermittently—say a truck-load or grabful at a time—or from a stock-heap. The elevator-buckets should ascend and meet the stream of material entering the elevator well, and not vice versa, or, better still, the feed should be spouted into the elevator leg above the well, as mentioned by Mr. Porter. In reply to Sir John Wolfe Barry, almost any kind of conveyor could be fitted beneath the deck of a large ship for conveying the coal to the far ends, or to any intermediate point; but only such conveyors as could deliver at any point would be suitable for the purpose. Undoubtedly the swinging conveyor could be used, and the coal could be deposited at the hold, in a hopper which communicated with one end of such a conveyor. Of course, the The Author.

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The Author. conveyor would have to be part and parcel of the ship, as it would take too much time to dismantle and re-erect it whenever the ship had to be loaded. There was, however, one class of conveyor which appeared to be more suitable for the purpose than any other. Being on the intermittent principle, this conveyor was not mentioned in the Paper. It was the invention of Mr. Hunt, and was largely used for filling coal-stores—work similar to that required on board ship. The appliance was inexpensive, and consisted of a line of rails and some self-emptying trucks: only the rails need be a fixture on the ship; the trucks could be removed and kept at the port for use with all vessels fitted with such rails. This conveyor was used for distances of 250 yards, so that it was long enough for the largest vessel. No driving-power was required, which was a point in its favour; and the man attending the apparatus need have no special training whatever. The capacity of such a conveyor would be 100 tons per hour for one line of rails, but several conveyors could of course be used for one vessel. The line of rails had a gradient of about 1 in 33 from the hold to the bulkhead, and upon it ran a specially constructed truck. As soon as the truck was full, it was released, and ran by its own weight to the point at which discharge was required, where it opened automatically and discharged its load, and then ran back uphill to the starting-point to be reloaded. A hopper was required, into which a coal-tip of any kind could discharge the coal, and from which the automatic wagons could be filled. When released, the truck ran down with steadily increasing velocity, so that by the time it approached the bottom of the incline the speed was considerable. Across the rails was arranged a cross-bar with which two projections on the descending truck came in contact, with the result that the bar was carried away in front of the truck for some distance. To the cross-bar was attached an endless rope connected to a counterweight. The momentum of the loaded truck was thus utilized in raising this weight, which, on being released, hauled the empty truck back to its starting-point. The bottom of the trucks was Λ-shaped, and there were two flap doors, one on each side, extending the whole length of the truck and hinged from the top at the ends of the truck. The doors were connected together by levers which, when released by an attachment fixed at the sides of the rails, opened the doors. The contents of the truck were thus immediately released on both sides of the rails, the form of the bottom of the truck preventing any coal from being spilt on the rails themselves. The empty truck was then hauled back by the descending counterweight, and, on

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its return to the starting-place, a simple operation closed the doors in readiness for another load. The same arrangement could be provided on both sides of a hold, and two or four lines of rails could take coal from a common hopper. Probably for loading ships a modification would be necessary, because a line of rails far enough from the deck to allow of the truck running between the deck and the rails would occupy too much space in the ship's hold; but he saw no reason why trucks similar to those described could not be built with wheels at the top, instead of at the bottom, so that the rails could be fixed close to the top of the hold. He was well acquainted with the installation described by Mr. Shoolbred, but as that method was also an intermittent system, it had had to be omitted from the Paper. The machine described by Mr. Molesworth, though a casting-machine, might be called a conveyor, as it was similar to the travelling-bucket conveyor. There were quite a number of them at work, principally in the United States. In England they had been adopted by the Millom and Askam Hematite Company of Millom[1] and by the Palmers Shipbuilding and Iron Company, of Jarrow-on-Tyne. The former company had the Uehling, and the latter the Heyl-Patterson machine.[2] The two machines did not differ much in general design, except that with the Heyl-Patterson machine the pigs were cast in the moulds while partly submerged in water; and, in order to prevent sticking, the moulds of the Uehling machine were coated with a spray of lime water, while in the Heyl-Patterson machine they were coated with soot. There were two other varieties of casting-machines, the Ramsay[3] and the Hawdon.[4] In the Ramsay machine the moulds were placed round the circumference of a large circle, while in the Uehling and Heyl-Patterson machines they were in a straight line. In the Hawdon machine the moulds were arranged partly in a straight line and partly in a circle. There were several Hawdon casting-machines at work in England, on the Continent, and in America. With reference to Mr. Molesworth's question about discharging from elevators, the diagram (*Fig. 43*) showed the curve described by the material discharged from the elevator. No matter with what velocity a body might be thrown off tangentially from the elevator-pulley, the moment it was free of its support the attraction of the earth asserted itself, and caused the body to fall. If the initial direction of motion was horizontal, as was the

The Author.

[1] *Iron and Coal Trades Review*, 1898, p. 912.
[2] *Ibid*, 1899, p. 952.
[3] *Engineering and Mining Journal*, 1901, p. 7.
[4] *The Engineer*, vol. lxxxviii. p. 111.

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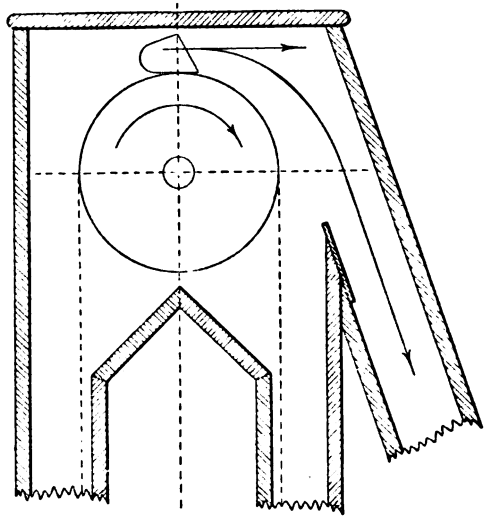
The Author. case with the delivery from an elevator, the attraction of the earth caused the body to move in a parabolic curve, and the heavier the body the more would its path deviate from the horizontal at every instant. A light body with a given linear velocity would proceed in an approximately horizontal line for a longer distance than a heavy body, as the earth's attraction was more or less counteracted by the friction of the atmosphere. He thought that Mr. Brown, when questioning the advisability of slanting elevators for coal, had had only gasworks and boiler-stokers in view. For such purposes there was no objection to the elevators being in a vertical position, because the coal had already been broken to a

Fig. 43.



small size, and a little additional breakage would be immaterial. As stated in the Paper, vertical elevators for heavy materials were objectionable on account of the high speed at which they would have to run in order to deliver the material down the discharge-shoot, and the consequent breakage. If breakage was of no importance, there was no objection to the fast-running vertical elevator. An elevator handling friable material, and running at its proper speed, must be wholly or partially inclined, in order to deliver satisfactorily. Inclined elevators possessed an undoubted advantage for heavy loads, as the load was dragged up on the inclined supports, and therefore did not hang on the top gear of the elevator with its whole weight. The speed at which elevators should run

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was given in the Paper for the ordinary type of elevator, in which the back of the bucket was attached to the chain or band. Buckets suspended from their sides, as shown in *Fig. 4*, were rarely used, and were adopted for convenience of discharging sticky materials, or where a slow-running elevator must be vertical. As a rule, such elevators would run at a lower speed than that stated in the Paper, in order to give the material time to drop out of the buckets. In this respect the construction must depend entirely upon the kind of material conveyed, and there was no occasion to go into the merits or demerits of various speeds of travel. The designs of push-plate conveyors were so numerous that within the narrow limits of a Paper it would be impossible to describe every one. The examples given in *Figs. 16* and *17* were approved designs by good makers, and were both in use in the gasworks at Nottingham, and at other places. The fact that the late Mr. Chester, who had had much experience with push-plate conveyors, had selected those two, proved their merit. The Author's own experience caused him to regard them with favour. In both, the friction between the coal and the trough occurred only at the bottom; and he did not think a narrow and deep conveyor-trough, such as that described by Mr. Brown, could be made at any less cost than a shallow and wider one. He had had the opportunity of seeing a conveyor of the same construction as *Fig. 17*, in a London electric power-station, where it had given satisfaction for a number of years, though the chain had lately shown such signs of wear that its renewal had become necessary. The appearance of this conveyor had proved clearly to him that the renewable bar at the bottom fulfilled its purpose, because he had found it brightly polished by friction against the chain. With reference to the point at which the push-plate should be attached to the chain, it would appear to any engineer that at or near the middle was the best place; for if the chain was attached to the top end of the plate there was a tendency for the latter to get out of square with the trough, and also a tendency for it to push itself away and ride over the top of the coal. He was unable to throw more light on the points raised in regard to the figures for the first cost of some of the conveyors, in the Table on p. 95; but he was sure that the cost of steam-engines, screens and crushers was not included in the cost of the different appliances. The installation illustrated in Fig. 32, Plate 2, was as complete a plant as could be desired for its intended purpose, namely, handling coal: it was not meant to deal with stones,

The Author

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The Author. railway brakes and broken wheels; and there was no machine known which would separate such articles from coal. A screen, which was occasionally provided, might or might not keep such articles back; but it would also retain large pieces of coal, which would have to be broken with a hammer in order to pass the screen. Such screens had usually a mesh of 6 inches, and might pass a piece of iron big enough to damage the coal-breaker. The only safeguard was to have a man to pick out any foreign matter that might be mixed with the coal. He had recently been informed by the engineer of a large gasworks that, beyond a miner's lamp and a blasting-cartridge, he had never found anything mixed with the coal. The cartridge had been in the scoop ready to go into the retort when it had fortunately been detected. If Mr. Brown had a device for keeping back such impurities, it would undoubtedly be of great interest to coal-users. The suggestion as to picking out the small coal was of little importance. The small coal dropped readily through the coal-breaker, which was set sufficiently far apart; and the addition of a screen as suggested would necessitate deeper excavation, which in most cases was objected to. The expense of making the excavation deeper, and the elevator longer, was not warranted by the slight advantage gained by the adoption of a screen. He agreed with Mr. Porter's remarks, and the practice of feeding elevators some distance above the neck of the elevator boot was a good one. It was especially applicable when the elevator was inclined, because then the buckets caught practically everything that came down the spout and allowed very little to drop into the boot. He could not agree with Mr. Helps as to the desirability of doing away with the boot altogether; in the event of anything from the shoot missing the buckets it would accumulate in the bottom, where it could easily be picked up, as it would contain no large pieces, and there would never be a sufficient accumulation to cause any trouble. Screw tightening-gears on band conveyors were practically the same, whether they were used for pushing or for pulling, and the use of either kind must depend upon circumstances. For long adjustments, the pulling action was undoubtedly preferable, as mentioned by Mr. Porter, because the screw was then in tension, and could be made of smaller diameter. Slimes would be rather difficult to convey with the swinging conveyor, but if a fall was available there would be no difficulty, provided the slimes were not too wet. The cable conveyor could also be used for this purpose; and probably it would be more suitable, as a large quantity of water could be run with the pulp, and the disks at intervals would prevent adhesion to

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the trough. Wet gravel could easily be conveyed with the swinging conveyor, but if the material was sticky the trough needed cleaning at intervals. This conveyor was used not only for conveying but also for sifting and classifying sand or gravel. It was not advisable to make it convey uphill; if the material was at all damp, a downward incline was better, even if only 1 in 100. Dry gravel or sand could be conveyed up an incline of as much as 1 in 20. The size of the gravel to be conveyed was quite immaterial. He thought Mr. Apjohn's statement, that nothing could be much better than the appliances used for dumping the whole of the contents of railway wagons into ships, was open to question. The appliances Mr. Apjohn referred to were largely used, and were probably the best that had been used so far; but why should a railway truck weighing 5 tons be raised 50 to 60 feet, in order to empty 10 tons of coal into a ship's hold? The structures for such coal-tips must be exceedingly strong, and the power required by the machinery, even with the balancing-devices in use, was enormous. Would not a tipping-device on the level of the rails, depositing the coal in a hopper (which required no driving-power), and inclined elevators for raising it, be much simpler, lighter and require less driving-power? The elevator, or part of it, could be made to swivel like a jib, and thus be raised or lowered to suit the position of any ship to be loaded. The speeds of band-conveyors given in the Table were the best economical speeds. There was no reason why they should not be exceeded; but if conveyors were worked at higher speeds than those given in the Table there was greater danger of breaking the coal at the point of delivery; so that it was more economical to make the appliances larger and work them at a lower speed. The four new coal-tips at Penarth Dock were capable of loading 2,154 tons in 2 hours. He failed to see the wisdom of running a band, designed to work at 400 feet per minute, at the speed of 700 feet per minute, as the coal would fly off nearly twice as far with the fast-running band as with the slow one, and the breakage at the higher speed must be disastrous. The electrically-driven scraper in America might be a useful appliance for trimming, and was also used for the purposes of unloading. With regard to coke, there was no difficulty whatever in conveying it with either a good band or the swinging conveyor. Such a swinging conveyor had been at work at the Margate gasworks for more than 2 years with great success. For conveying hot coke the best conveyor was probably the De Brower, consisting of two chains concealed in the sides of the conveyor-trough, and connected by bars which pushed the coke along in the trough.

The Author.

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3 March, 1903.

JOHN CLARKE HAWKSHAW, M.A., President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

FREDERICK WILLIAM BESANT.
THOMAS DUNCANSON.
JOHN EDWARD EVERETT.
GEORGE LACY GOOD.
JAMES KENNETH GUTHRIE.
DANIEL LEAN HUTCHISON, M.Sc.
CHRISTIAN KUSSMAUL.
JOHN RUMNEY NICHOLSON.
JOHN JAMES ROBSON.
WILLIAM ROSS, B.E., B.A.
The Hon. LOCKHART MATTHEW ST CLAIR, C.I.E.
EDWARD MARSH SIMPSON.
HAROLD DUKE SMITH.
FREDERICK ORLANDO STEPHENS.
ALEC GEORGE VAUGHAN-LEE.

And that the following Candidates had been admitted as

Students.

EDWARD HENRY D'ESTERRE DARBY, B.A.
LOUIS HENRY ARMISTEAD GAUNT.
DOUGLAS OWEN MILNER MOORE.
HENRY MORAN.
ARTHUR HAROLD STEVENS.

The Candidates balloted for and duly elected were: as

An Honorary Member.

The Rt. Hon. the Earl of CROMER, G.C.B., G.C.M.G., K.C.S.I., C.I.E.

Members.

VINCENT SIDNEY ALLPRESS.
HAROLD BARLOW.
FARIE BURNET.
ROBERT MUIR FERRIER, B.Sc.
GEORGE MOORE.
DAVID EVAN ROBERTS.
REGINALD ROBERT TODD.

Associate Members.

EDGAR LIONEL BENJAMIN.
ARTHUR CURTIS CRAWLEY-BOEVEY, B.A.
THOMAS EDWARD HETT HEYWOOD, Stud. Inst. C.E.
FRANK GORDON LAGERWALL, Stud. Inst. C.E.
ROBERT JAMES LONGLEY, Stud. Inst. C.E.
RUSTOM KAIKHASRO NARIMAN, Stud. Inst. C.E.
RICHARD FRANCIS MARY O'CONNOR B.E., B.A.
ARTHUR CAMPBELL PADDAY.
LIONEL FORTESCUE WELLS, B.Sc., Stud Inst. C.E.
RUPERT GREAVES WILLIAMS-ELLIS, B.A., Stud. Inst. C.E.
WALTER HARTLEY WISWALL.

Associates.

GEORGE CHARLES FREDERICK, *Commander* R.N.
JOHN MATHIESON.

The discussion upon the Paper by Mr. G. F. Zimmer, on "Mechanical Handling of Material," occupied the evenin.

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10 March, 1903.

JOHN CLARKE HAWKSHAW, M.A., President,
in the Chair.

(Paper No. 3366.)

"The Irrigation-Weir across the Bhadar River, Kathiawar."

By JOHN JAMES BOURNE BENSON, Assoc. M. Inst. C.E.

THE Bhadar River drains 4,000 square miles of the interior of Kathiawar, and discharges into the Indian Ocean near the middle of the straight coast-line of the Peninsula (Fig. 1, Plate 3). The catchment-area is composed of rocky hills and extensive plains, and receives a mean annual rainfall of 27·7 inches, most of which falls in about 3 months. Except in years of short rainfall there is a perennial flow. The present shore-line appears to have risen, enclosing shallow lakes, which have silted up by the deposit of mud brought down by the river-floods. Except where the land is still below high-water level, the low alluvial lands now contained within this area are cultivated, and form the delta of the Bhadar River. There are 60 square miles of such land, called the Mokul Rann, and the works described in this Paper were undertaken with the object of reclaiming the waste area, and of irrigating it along with about 20 square miles of cultivated land.

Floods have continued to deposit silt on these low lands, both waste and cultivated; but the level of the Rann lands has not risen appreciably in modern times. Owing to the salt rendering the soil extremely friable, and in the hot weather dusty, the silt deposited annually by floods was blown off the land as dust by the high winds; the land was submerged only at spring tides, and the silt which accumulated during the months of July, August and September was blown away between November and July. In 1894 the Author proposed to exclude the sea-water by a dam at Gosa Bara (Fig. 2), and this was built in 1895. It is 1,800 feet in length, and 8 feet in depth at the deepest part; and it effectually

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excludes the sea from the greater part of the Rann. The construction of the weir forming the subject of this Paper completed the reclamation of the Rann by permanently retaining the silt, and preventing the formation of salt-dust. The effect of the reclamation, since 1898, has been a rise of 2 feet in the level of a large area of the Rann, where the bulk of the silt is deposited. Dust is not raised now even by storms; whereas formerly it was not possible to cross the Rann on a windy day, owing to the dense dust-clouds.

Site of Weir.—The tidal part of the estuary of the River Bhadar extended for 14 miles from the sea (Fig. 2, Plate 3). The extreme variation of tide is only 8·50 feet at the river mouth, *i.e.*, between R.L. 78·00 and R.L. 86·50. The levels of the same tides at a distance of 8½ miles up-stream were between R.L. 80·00 and R.L. 86·00. The bed of the estuary is nearly level for 7 miles (between 1½ mile and 8½ miles up-stream). The width contracts uniformly from about 600 feet at 1½ mile from the sea (the site of the weir) to 300 feet at 8½ miles from the sea. The cost of a weir built at the latter point would probably have been only two-thirds of the one completed; but 136 million cubic feet of storage capacity would have been lost, and the 7 miles of river bordered by rich land would have been left in the condition of a tidal estuary. Also the velocity of the river-floods is less at the lower site, owing to the low banks allowing the floods to spread over the Rann and to be absorbed. It was therefore decided to build the weir at the site nearer to the sea.

General Design.—The weir (Fig. 3, Plate 3) offers but little resistance to the passage of floods, as its sill is only 2 feet above lowest spring-tide level. The cross-sectional area of the river up to the banks R.L. 88·00 at the weir was 6,329 square feet. The actual waterway left by the weir is 4,060 square feet, or nearly two-thirds of the total cross-sectional area up to the same level. The actual waterway up to flood-level is 9,215 square feet; but this is immaterial, as it provides for only an insignificant part of the flood-discharge. In Indian weirs the ratio which the area of the sluices bears to the total obstruction offered by the weir when they are closed is between 1 : 6 and 1 : 12. The soft nature of the banks made it appear possible that the Bhadar River might change its course if seriously obstructed, and it was therefore determined to have a much opener weir. The fact that the weir would be managed by natives without much supervision was kept in view in the design; it was made as simple and strong as possible, and is in fact a bridge having a floor or sill which is temporarily raised by

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wooden shutters to hold up the river-water. The results of preliminary borings proved that rock existed at reasonable depths; and it was therefore decided to build a masonry weir on wells sunk to the rock and filled with rubble masonry in lime mortar. The weir has twenty openings, each 24 feet in width, closed with shutters 8 feet in height; and one lock 20 feet in width and 11 feet depth over the sill. The piers, 29 feet 6 inches apart from centre to centre, are 18 feet in height to the arch springing-level, and support movable shutter-beams at a level of 10 feet above the sill. The arches are 25 feet in clear span, and 10 feet in width. The lock is spanned by a pivoted bridge, the roadway of which is 10 feet in clear width between the railings. The sluices are worked entirely from the road.

Construction.—The whole of the lock-abutment and the pier-foundations are built on wells sunk to the rock (Figs. 4, Plate 3). The sill is founded on wells sunk to the rock where this is met with at a depth not exceeding 12 feet below sill-level; elsewhere the wells are founded on clay at a depth of 14 feet below sill-level. The difficulty of sinking square wells in clay, and the unsuitability of circular wells, led to the adoption of square wells with rounded corners. These wells were built of fine-dressed coursed masonry on a cement-concrete curb, which was moulded in a wrought-iron movable mould. The moulds were generally removed after 4 days, but the curbs were not built upon until after 7 days, and were sunk after 15 days. The cutting edge of the curbs was found to be strong enough; but the coursed masonry of the well had usually to be plastered with cement in order to reduce friction in sinking. The wells were sunk without difficulty to a maximum depth of 36 feet, with a weight of 30 tons. The water was then pumped out, cement concrete was filled in to a depth of 2 feet, and upon it was built rubble masonry with lime mortar to the level of the sill course. The work proceeded from the lock end of the weir. The clay material excavated from the lock was thrown across the estuary in the form of two dams, enclosing sufficient area in which to place the wells of the lock and of seven spans of the weir When the masonry of these wells had been built to above sill-level, the remaining half of the river-channel, in which there was 14½ feet depth of water at high tide, was enclosed with clay dams. The lowest part of the river-bed was 8 feet below sill-level, and this had to be filled; it was therefore only necessary to remove the upper 12 feet of the clay dams on the completion of the work.

The following plant was used in the work:—One 16-HP. oil-engine, one 10-inch centrifugal pump, one 10-HP. portable engine,

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one 8-inch centrifugal pump, one pulsometer, hand-pumps, etc., one 3-ton steam-crane, two 2-ton hand-cranes, two Bull dredgers, each of 20 cubic feet capacity, and smaller grabs.

With the exception of the rubble-masonry filling in the wells, all the masonry is fine-dressed coursed ashlar, built in hydraulic-lime mortar. The lime was burnt on the banks of the Minsar River, 16 miles from the work, where the kunkur was found. The sill, lock, quoins and coping were built in Portland cement.

The use of iron in the permanent work was limited to the channels for the shutters, the necessary bolts and sluices in the teak lock-gates, the shutter-beams, and the brackets on them. The piers are built with vertical faces throughout, but have their thickness reduced abruptly at the beam-level. The cut-water is semicircular on plan, and is built to a batter parallel to the slope of the shutters; on the down-stream end the piers are stepped, which is a more convenient form of construction. The springing-level of the arches is 1½ foot above the highest observed flood-level. The railings are fixed permanently on the down-stream side of the bridge and over the piers on the up-stream side, leaving a gap of 21 feet over each of the weir-openings, which is closed by chains when the weir is not being worked. A single rail for the cranes to run on is laid along the centre of the roadway. As the traffic consists chiefly of carts drawn by pairs of bullocks, and their tracks are clear of the rail, the latter causes no inconvenience.

The weir is closed by 240 shutters, each 4 feet square, in two rows of 120, one above the other. Those in the lower row are chiefly of Haskinized pitch-pine 3 inches in thickness, but some are of 2½-inch teak. Those in the upper row are all of 2-inch teak, and slide in H-shaped rolled-steel guides (Figs. 5, Plate 3) which rest on the 6-inch by 3-inch steel channels built in the cement sill. The five guides in each span are supported at the top by five brackets fixed to the beam. Each alternate bracket contains a catch, which can be released automatically, thereby throwing down three guides in each span and completely opening the six bays of shutters in the span. Ropes are run through rings in the shutters, and attached to hooks on the lower side of the beam, in order to prevent the shutters from being washed away when the weir is suddenly thrown open. The remaining two brackets support the guides at a point level with the top of the beam, thereby nearly neutralizing the twisting strain thrown on the beam by the three catch-brackets. The weir is usually opened, however, by removing first the upper row of 120 shutters, before any in the lower row are raised. This prevents undue scouring,

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which would take place if the full 8 feet depth of shutters were removed from any span at one time. The steel guides are then removed; and lastly the beams are raised, and are laid on stone brackets above flood-level. The shutters and guides are stacked on the two approaches, which for this purpose are widened out to 22 feet in width, and are formed level with the abutments. The width of the road is maintained at 10 feet, and the extra 6-foot width on each side of the road is enclosed for the shutters, etc. For raising the shutters, guides and beams, two simple portable cranes are used, which run on the single central line of rail. When the cranes are lifting a load, the jibs rest on the curb-course; and when they are being shifted from span to span the jib just clears this course. Both cranes are required for lifting a beam, and two gangs of eight men have removed the whole of the 240 shutters in a day of 8 hours. The pay of both gangs is equivalent to 6*s.* 8*d.* The H-guides and the beams can be removed in 1½ day, and can be handled even when the river is in flood. The lock-gates have also to be opened before the monsoon floods. This is easily accomplished when the weir is open and the tide is rising; but, if there happens to be a slight flood at the time, it is necessary to place shutters across the lock, above or below the gates, and for this purpose beams, H-guides, and channels in the sills are provided. During the monsoon the lock-gates are securely held open, in the deep recesses provided for them, by rails of suitable length, which have their ends bent downwards at right angles, and are laid across the full width of the lock-wall. The lock is bridged by a pair of 12-inch by 6-inch rolled-steel beams, 36 feet in length, weighing 36 lbs. per lineal foot, braced together with angle-bars supporting a floor of teak. The bridge is pivoted, and is provided with balance-weights, so that one man can open it in order to allow sailing-boats to pass.

Subsidiary Works.—The subsidiary works already carried out can be described in a few words: extensions will be required later, but only as new villages are built.

The main drain, 12 feet in width at the bottom, discharges at the mouth of the Bhadar through three tide-sluices, having a total width of 21 feet. It is connected with each of the natural channels (Sanbu and Hugli), so that the water in these can be run out if it becomes brackish. Four bridged, and two shallow, regulators are provided, for enabling each channel to be filled separately and run out if required; and across the Ojat River channel there is a masonry weir, 300 feet in length, which is being fitted with falling shutters

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5 feet in height, and will act as a regulator; meanwhile it is temporarily closed with clay once a year. There are also four occupation road-bridges over canals. When the weir is closed the water in the river rises to R.L. 88·00, and then the regulators at Delodar and Mitrala are open, and the natural channels are filled to Kesod and Gosa. The total length of the water-channels is 62½ miles, including the river-bed. The canals from the north of the river, and to Garej on the south, were cut to serve the intermediate land, and also to fill the Sanbu and Ojat channels in abnormally dry years. It is difficult to keep open the Sanbu channel near Mitrala, because its bed is sandy and floods choke it; it therefore has to be filled occasionally from the canal. The whole area of the Rann is commanded by the Bhadar when at full-supply level. But in order to irrigate the 12,000 acres of land now under cultivation, water has to be raised to a height varying between 8 feet at Mitrala and 1 foot near the weir. The cost of raising the water is small, and the land requires no drainage, as the water is used sparingly and carefully.

Working of the Weir.—The floods of the 31st July and the 14th August, 1900, were of unprecedented height, and brought down enormous quantities of brushwood and trees. The ⊢-guides over one-half of the weir had inadvertently been left standing; and the openings were blocked to a depth of 6 feet, and to a distance up-stream of 50 feet, with brushwood, silt and palm-tree trunks, of which last over a hundred were removed. Many of them were 40 feet in length, and lodged across from pier to pier. Much difficulty might have been experienced in clearing the weir, but for a remarkable occurrence. The mouth of the river had become closed with a sand-bar to a height of several feet above high-tide level; and when the whole of the low-lying land was submerged to a depth of several feet, there ceased to be any appreciable flow in the river. After this stagnation had continued for some hours, a slight up-stream movement of the water was observed, due to a flood in the Ojat River which joins the Bhadar just below the weir. The accumulation of trees was thus loosened and removed, and the weir was then completely opened. These floods submerged over 100 square miles of the low-lying land, and attained a depth of 12 feet on the Rann. At 9 p.m. on the 31st July the sand-bar was carried away, and the water commenced to escape. It was then observed that the site of the weir had been well chosen, as it was just above the area in which the velocity of the floods was excessive. There was a difference in level of 12½ feet between mean sea-level and flood-level, and owing to the con-

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figuration of that part of the delta, this fall was concentrated in a length of 1 mile. The velocity was so great in this mile that the masonry parapets of two bridges over the main drain were washed off, while between Sikasa and the weir, 1½ mile from the shore, small sailing-boats were used with safety. On the subsidence of the floods, in August, the shutters were placed in the weir; but the flow was still so great that the stone filling, 3 feet in depth, and consisting of stones 2 to 4 cubic feet in size, was washed out; and in two spans, the sixth and the twentieth from the lock, scouring took place to a depth of about 15 feet below the level of the sill, which, however, with its wells, was not damaged. Across these two spans 6-inch teak sheet-piling was driven, and the weir was closed in September. Up to December, the flow was 600 cubic feet per second. Shortly afterwards, the whole length of the weir was paved, between the piers and on the lower side of the sill, with a 10-inch thickness of ashlar paving in Portland cement, on a Portland-cement concrete bed. This work could be done only at low tide. No trouble was given by the river-water, as the weir was water-tight under a head of 10 feet. A similar paved floor should be laid on the up-stream side of the sill, in order to add to the strength of the weir. The weir was opened again in June, 1901, in anticipation of the monsoon; but the monsoon failed in Kathiawar, where the rainfall measured at Porbandar was less than 3 inches during 1901. The tide was allowed to enter the estuary for 2½ months, until the weir was closed again in September, 1901, when there was sufficient flow in the river to fill the bed to the crest of the shutters. The flow was only 50 cubic feet per second in October, and ceased entirely on the 15th November. The impounded water was drawn off by the 23rd December, and since then the shutters have been subjected to back-pressure, having to exclude the sea-water. Thus during the 2 years the weir has been in use, a season of phenomenal rainfall and flood has been followed by one of unprecedented drought.

The abundance of water available during the season September, 1900, to June, 1901, was not fully utilized, on account of the seven villages concerned having been almost depopulated by the famine of 1899–1900. During the season September–December, 1901, one good crop was obtained by irrigation in two villages; but several other villages sowed too late and lost their crop, owing to the river drying up in December. As experience is gained, more benefit will be derived from the work until the whole 30,000 culturable acres of the Rann and the 12,000 acres adjoining the river and canals are irrigated. The soil is so clayey that moisture is

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retained for months; for example, a field somewhat low-lying, 2 miles above the weir, which was flooded during July and sown with Bajri (spiked millet), produced a good crop, although no rain fell and it was not irrigated. Gram (pulse) and wheat do not require irrigation here, if the land is thoroughly watered before sowing. Therefore, when water is plentiful in October and a flow of 200 cubic feet per second is available, a large area of land can be watered for these crops. The grain-crop (Jowari), which requires irrigation to the extent of 100,000 cubic feet per acre, can be sown later, up to April; and if the water holds out, as it will do in normal years, hot-weather crops and fodder can be irrigated. During the monsoon of 1902 it was found that the paving was not wide enough to prevent scour immediately beyond it, when only a few spans were opened automatically. It will be necessary to extend the paving down-stream, and to sink a line of wells in order to ensure safety in the event of a flood occurring at night, and opening only a few spans automatically, while leaving the remainder closed.

Rainfall.—The annual rainfall for the period 1886–1901 at four stations in the Bhadar river-valley is shown in the Appendix, Table I. Taking as unity the mean fall of 27·70 inches during these 16 years, the fall in the wettest year was 1·75, and in the driest year 0·22. The average fall in the wettest four consecutive years was 1·38, and in the driest four consecutive years 0·70. The variations in the perennial flow, which were also great, are shown in Table II., and fairly accord with the rainfall. The rainfall occurs chiefly during the 3 months, 15 June–15 September, half of it falling during July (Table III.). The springs have therefore to maintain the flow during 9 months. An unprecedented fall on the 31st July and the 1st August, 1900, did not raise the springs to any extent. The run-off must have been almost equal to the fall after the surface of the land had become saturated. On the second of these days a rainfall of 23 inches in 11 hours was gauged on the railway, 18 miles north of the weir. On that day a run-off of 1 million cubic feet per minute from the catchment-area of 11·3 square miles was gauged approximately.

Cost.—The costs of the chief items of the work are shown in the Appendix, Table IV. The total cost of all the works referred to in the Paper (except the Gosa Bara dam, which cost 43,000 rupees, or £2,867), including plant, but excluding establishment-costs, was 3,11,017 rupees, or £20,734, which was within the amount sanctioned by the Bombay Government in November, 1895. The work was initiated, designed, and carried out by the Author.

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The remarkably low cost of the works was partly due to the cheapness of material and labour in Kathiawar.

Conclusion.—An attempt has been made, and it is believed successfully, to utilize the flow formerly allowed to run to waste into the sea. The flow is neither so large nor as uniform as might have been expected from a catchment-area of 4,000 square miles; but permanent springs cannot be looked for in the geological formation general throughout this province. There is no rock which takes the place of chalk as a water-bearing stratum; and the rain falls chiefly during one month in the year, and is frequently concentrated in heavy falls, of which the bulk runs off at once. There is only one remedy for this, namely, the construction of storage-tanks on the tributaries of the River Bhadar. A beginning has been made by the States of Jasdan and Gondal, on the advice of Mr. E. O. Mawson, and Porbandar (under the Author): four tanks, having an aggregate capacity of 1,600 million cubic feet, and other smaller tanks, have been built; and an additional tank to contain 600 million cubic feet is in progress in Gondal (Fig. 1). At least eight more tanks could be built, which, with the existing tanks, would provide for the storage of 10,000 million cubic feet. The cost should not exceed 50 lakhs of rupees (£333,000), and one-twelfth of the cultivated area in the valley would be irrigated; while a much larger area would be benefited, by having the subsoil water-level raised.

The Paper is accompanied by twelve photographs, and by two drawings from which Plate 3 has been prepared.

[APPENDIX.

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APPENDIX.

TABLE I.—ANNUAL RAINFALL AT FOUR STATIONS IN CATCHMENT OF BHADAR RIVER, KATHIAWAR, 1886–1901.

Stations. (Fig. 1, Plate 1.)	Miles above Mouth.	Height in Feet above Sea-Level.	Average Inches. 1886–1901.	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901
Jasdan . . .	113	830	29·06	34·20	26·95	18·65	34·53	26·70	35·52	41·89	23·72	49·31	22·95	27·44	37·75	21·74	6·16	37·12	20·29
Gondal . . .	88	506	25·37	40·43	28·57	17·76	27·80	15·79	27·51	29·50	29·15	44·66	15·26	24·62	28·62	20·88	3·89	39·78	11·72
Jetalsar . . .	60	284	28·16	40·65	26·48	15·22	36·27	21·83	33·24	35·91	36·00	56·56	16·94	24·00	32·48	16·96	6·09	45·14	7·37
Dhoraji . . .	49	189	28·23	42·12	24·82	13·97	37·21	14·70	47·44	38·93	38·39	43·52	16·30	28·20	30·48	16·01	8·24	48·61	7·72
Mean or average in valley . .	..	..	27·70	39·35	26·70	16·40	33·95	19·63	35·98	36·56	31·81	48·51	17·86	26·06	32·33	18·90	6·09	41·41	11·77
Ratio to mean, as unity . . .	..	..	..	1·42	0·96	0·59	1·23	0·70	1·28	1·32	1·15	1·75	0·64	0·94	1·17	0·68	0·22	1·49	0·42
Junagadh[1] . .	45	600	42·72	50·44	45·48	21·54	33·95	19·63	35·98	36·56	31·81	62·69	30·67	33·00	49·74	18·98	8·75	62·23	11·61

	Per Cent.	
Wettest four consecutive years (1891–1894)	38	above mean.
Driest „ „ „ (1898–1901)	30	below „
Wettest year (1894)	75	above „
Driest year (1899)	78	below „

[1] This station is in part of the catchment discharging below the weir. The perennial flow is diverted into the Bhadar.

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TABLE II.—PERENNIAL FLOW IN BHADAR RIVER, 1892-1901.

Date of Gauging.	Flow: Cubic Feet per Second.	Due to a Rainfall in the previous Year of—	Remarks.
		Inches.	
14 March, 1892	175	35·93 in 1891 (1·28).	N.B.—The rainfall is generally confined to the 3 months 15 June to 15 September.
20 May, 1892	80		
26 May, 1893	100	36·56 in 1892 (1·82).	
26 February, 1894	185	31·81 in 1893 (1·15).	Mean rainfall during these 4 years was 33·20 (1·38).
15 March, 1894	145		
18 April, 1894	110		
11 December, 1894	550	48·51 in 1894 (1·75).	This was the wettest of the 16 years in Table I.
2 March, 1895	190		
31 December, 1895	350	17·86 in 1895 (0·64).	
1 March, 1896	90		
1 May, 1896	50		
15 December, 1896	325	26·06 in 1896 (0·94).	
15 January, 1897	225		
15 February, 1897	125		
15 March, 1897	100		
19 April, 1898	110	32·33 in 1897 (1·17).	Mean annual rainfall during the 4 years 1898-1901 was 19·54 (0·70). If an extraordinary fall of 40 inches in 3 days were omitted, the mean fall would be 9·54 (0·34).
1 February, 1899	Stopped	18·90 in 1898 (0·68).	This meagre fall was insufficient to maintain the subsoil-water at normal level, and hence the river dried.
1 December, 1900	600	41·41 in 1900 (1·49).	In 1899 the river remained dry, as only 6·09 inches of rain fell during the 22 months October, 1898, to July, 1900.
15 November, 1901	Stopped	11·77 in 1901 (0·42).	

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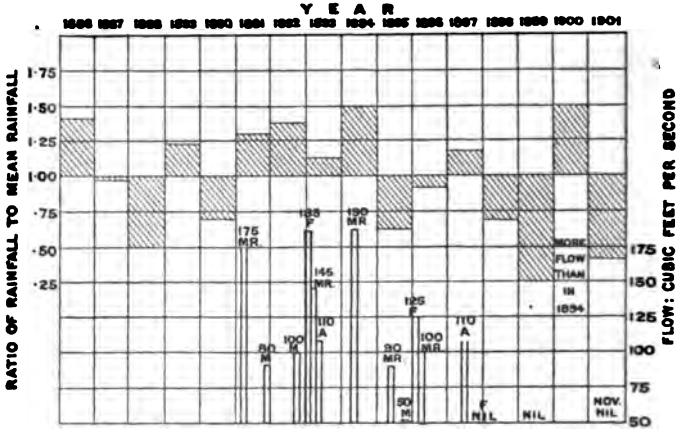
DIAGRAM FROM TABLES I. AND II.



NOTE: $\frac{185}{F}$ = February perennial-flow gauging, etc.

$\frac{100}{M}$ = May " " " "

The perennial-flow gaugings are shown under the year in which the rain fell that fed the flow, *e.g.*, the 1895 flow is shown under 1894.

TABLE III.—MEAN MONTHLY RAINFALL DURING 11 YEARS (1882–1892).

From Government Gazette, Part III. of 1895.

Station in Bhadar Valley. (Fig. 1, Plate 1.)	Miles above Mouth.	Height in Feet above Sea-Level.	May.	June.	July.	August.	September.	October.	November.
Jasdan	113	830	0·33	3·14	15·71	6·55	7·22	1·40	0·51
Gondal	88	506	0·31	3·69	15·14	4·38	3·94	0·72	0·33
Jetalsar	60	284	0·20	4·61	16·72	4·13	4·51	1·19	0·57
Dhoraji	49	189	0·33	3·14	15·71	6·55	7·22	1·40	0·51
Mean fall in inches . .	..	..	0·25	3·64	15·82	5·40	5·72	1·00	0·48
Junagadh	45	600	0·23	5·91	24·16	6·60	4·48	0·80	0·40
Porbandar	20	30	0·50	5·22	15·42	3·31	2·72	0·31	0·67
Mean fall in inches . .	..	..	0·36	5·56	19·79	4·95	3·60	0·55	0·53

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TABLE IV.—COSTS OF THE WORK.

Amount of sanctioned estimate, 313,500 rupees = £20,900.

Cost of work, plant, etc., excluding establishment costs, 311,017 rupees = £20,734.

Quantity.	Item.	Rate. £	s.	d.	Amount. £	s.	d.
Cubic Yards.							
11,111	Rock excavation	0	2	6	1,388	17	6
100,000	Earth excavation in canals	0	0	1·35	562	10	0
54,626	Clay excavation in foundations	0	0	7·29	1,659	5	4
3,316·5	Dredging in wells	0	3	11	649	9	7
1,163	Coursed masonry in wells	0	14	6	843	3	6
2,710	„ „ „ superstructure	0	13	4	1,806	13	4
2,363	Rubble masonry in filling wells	0	6	9	797	10	3
251	Portland cement, filling wells, in coping, sills, and lock quoins	1	0	1	252	0	11
523	Portland cement concrete in curbs	1	10	9	804	2	3
170	Lime concrete in curbs	0	3	11	33	5	10
7,784	Rubble stone filling	0	2	7	1,005	8	8
6,713	„ „ pitching	0	3	5	1,146	16	1
732	Masonry in arches, paving and cornice	0	14	6	530	14	0
Cubic Feet.							
1,200	Moulmein teak and Haskinized pine complete in work	0	5	4	320	0	0
	Plant				1,666	0	0
	Pumping (approximate)				1,000	0	0
	Regulators, bridges, and works in weir not detailed above				6,268	2	9
	Total			£	20,734	0	0

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(Paper No. 3379.)

"Recent Irrigation in the Punjab."

By SIDNEY PRESTON, C.I.E., Assoc. M. Inst. C.E.

IN his Presidential Address to the Institution, delivered on the 5th November, 1901, Mr. Charles Hawksley said, with regard to the progress of irrigation works in India during the past century, "In England these great works are seldom heard of, and I cannot but think that the magnitude of some of them, and the difficulties which the engineers have encountered in their execution, are but little appreciated even by many members of our own profession."[1]

Perusal of the above has induced the Author to write this Paper, in the hope that it may give the profession in England an idea of the latest development of irrigation science, whereby vast tracts of land, which before the introduction of irrigation bore only a scrub jungle, and gave scanty and precarious support to herds of cattle, are being converted into the most prosperous areas in Upper India.

Of the various systems of irrigation in India a general description will be found in Mr. R. B. Buckley's book,[2] perusal of which will well repay any one interested in the subject. In the present Paper the most modern scheme only will be considered; the general scope of the project, and the details of distribution of the large volume of water dealt with, will be explained, as well as the responsibilities of the engineers for its administration after construction.

THE CHENAB IRRIGATION SCHEME.

The scheme selected for description is that of the Chenab Canal for irrigating the immense tract of country between the Ravi and Chenab Rivers known as the Rechna Doab. The Author has selected this scheme because, although not absolutely the latest, it

[1] Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 23.
[2] "Irrigation Works in India." London, 1893.

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is largely finished, and therefore some statistics can be given showing what it has already done, and from these its prospects for the future can be deduced.

The Rechna Doab has two main features. The large area, amounting to about 3,029,300 acres, contained within the line of black crosses on the general map (Fig. 1, Plate 4) is all Crown waste land; the remainder is land which is already comprised in the limits of settled villages or communities, although, before the introduction of irrigation, a considerable portion of it was lying waste, owing to the smallness of the population and the difficulty of cultivation without artificial irrigation. In these settled communities the land of any cultivator may be distributed in small patches all over the village limits; and the most that has hitherto been attempted is the construction of a government channel leading the water to the boundary of each village; leaving it to the villagers themselves to distribute it within those limits, according to the area owned by each person. For the development of the waste lands, it was necessary to bring in settlers from other over-populated districts of the Province; and in order to induce them to emigrate, it is necessary to give some promises, which it is unnecessary to give to men who have been settled for generations on their own land, and to whom, by the government channel, a source of wealth is brought without any exertion on their part.

The cultivator in a settled village who, from the fact of his land not being commanded by the canal as designed, or from the ill-will of others in the village, does not get a share of the water, is in no worse position than he was before the canal was made; he can still cultivate with the aid of rain or a well, as he did formerly. On the other hand, the waste lands have become waste because the rainfall was too small to support cultivation, and the water too deep below the surface to permit of wells being worked. It is therefore necessary to guarantee that each settler on waste land shall obtain a fair area of matured crops. In order to ensure this, and to make the cultivation of the tract a success, it was found that the water must be led in a properly constructed and regularly graded channel to the commanding point of each holding, before the settlers are brought in; and this is the main feature of the Chenab Canal, and the one which distinguishes it from any other previously constructed by Government.

Before operations are begun on the waste land, some of it is well wooded, with three or four kinds of jungle growth; and this portion bears also a good crop of grass fit for grazing when there

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is favourable rain. Some of the land is covered with a small scrub and camel thorn; and some is absolutely bare, producing nothing but a brilliant mirage, which has often deceived the engineers into thinking a big breach has occurred, flooding many miles of country.

Design and Construction of the Chenab Canal.

Original Design.—The Chenab Canal was originally designed and constructed as an inundation canal, to irrigate a portion only of the total area now commanded, as indicated in the general map (Fig. 1, Plate 4). An inundation canal is one which flows only in the hot weather and rains, when the floods in the river are at a level high enough to give a working depth in the canal. Such a system is suitable only for the irrigation of riverine lands in which the subsoil-water is so near the surface that the irrigation effected from the canal can be supplemented, when flow ceases, by water lifted from wells. Inundation canals are quite unsuited to form the only source of supply to crops on high land, with the subsoil water-level more than 100 feet below ground. For such land a continuous and assured supply is necessary, particularly when the land is to be developed by imported settlers. The necessity was fully realized by many of the engineers at the time the canal was originally constructed; and it is to be regretted that they were unable to convince the responsible officers of the Government of India, whereby much delay and some expense would have been saved.

The canal was constructed with a bed width of 109 feet, and a longitudinal slope of 1 in 6,250, and was intended to carry a depth of 7·4 feet of water. No weir was constructed across the river to force the supply into the canal, and it was soon proved practically that this was a necessity; for the heavy deposit of silt brought down by the river in flood so choked the head reach that the supply in the canal failed before the hot-weather crop was matured, or before ploughings, for which water is required, were completed for the cold-weather sowings. As a consequence, it was decided to construct a weir across the Chenab at a point about 6 miles above that at which the original canal took out. A Paper on this weir[1] has been presented to the Institution by the builder, the late Mr. L. F. MacLean, C.I.E., M. Inst. C.E., and it is therefore unnecessary to refer to it further. A channel of the same dimensions as the original was at the same time dug to

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 314.

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connect the weir with the old canal; and this accounts for the peculiar bend in the main line at the end of the eighth mile. The new channel and the weir were completed in March, 1892, at which time the Author assumed charge of the whole canal as superintending engineer.

Enlargement of the Canal.—When the Government of India had decided to recommend the conversion of the inundation canal into a perennial one, it was recognized that the full value of the weir would not be obtained unless the canal was extended so as to command as much of the Rechna Doab as possible. An estimate was therefore prepared in 1891, and sanctioned in 1892, for extending irrigation to the larger tract shown on the general plan. This necessitated widening the first 28 miles of the main line of canal from a bed width of 109 feet to 250 feet, and the remaining 12 miles to 150 feet; while it was proposed to increase the depth of full supply from 7·4 feet to 9·6 feet.

It was calculated that such a channel, with side slopes of 1 to 1 and the original longitudinal slope of 1 in 6,250, would discharge 8,333 cubic feet per second [1] if N in Kutter's formula was estimated at 0·025; that being the coefficient for earth in channels of tolerably uniform cross section, inclination and direction, in moderately good order and regimen, and free from weeds and stones. After the channels have been running for some years, however, and the fine alluvial silt brought down and deposited by the water has filled up the irregularities in the sides and bed, they seem to approximate more closely to channels lined with rubble masonry or to channels in gravel well rammed and carefully trimmed; for observations of actual discharge have been found to give coefficients of 0·020 and 0·018. Indeed, the Author has known the results of careful observers to give coefficients as low as 0·017 and 0·016. The effect has been that the Chenab Canal, with the section stated above and running a depth of 10·8 feet, instead of the 9·6 feet for which it was designed, is found in practice to discharge a volume of 10,800 cubic feet per second. This is the maximum yet obtained, but will probably in its turn be exceeded, when the consolidation of the earthwork permits an even greater depth of flow. The increase in the volume has already permitted the extension of the distributaries beyond the limits proposed in the estimate of 1891, as is shown by the government channels extend-

[1] The term "cusecs," which was originated by Sir Thomas Higham, K.C.I.E., M. Inst. C.E., is in general use throughout the Irrigation Department in India as an abbreviation for "cubic feet per second."

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ing beyond the boundary line of the enlarged scheme in Fig. 1, Plate 4. It is now believed that the canal will be able to carry a volume sufficient to give an ample supply to the whole of the area requiring irrigation between the two rivers: and estimates are being prepared of the cost of the channels required, which will unquestionably be sanctioned in due course.

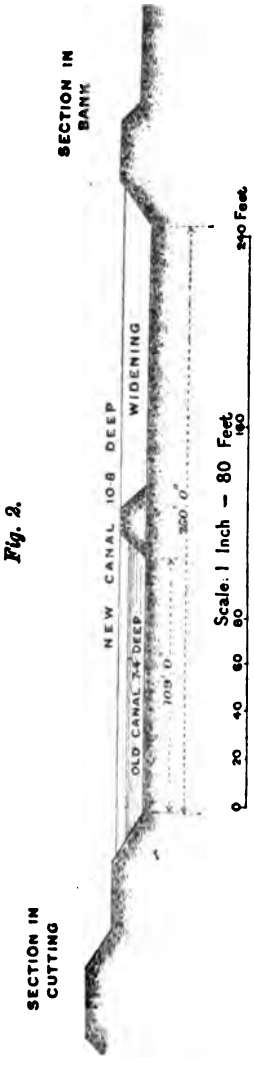

Fig. 2.

In addition to earthwork in the widening of the main canal, all the bridges had to be rebuilt, as those originally provided had been given a timber superstructure, which was suitable enough for a canal that would be in flow for only 3 or 4 months in the year. As it was necessary to remove the superstructure in order to enlarge and raise the bridges to suit the new section of channel, the opportunity was taken to replace the timber bridges with fine arched structures of eleven spans of 22 feet.

It was also considered necessary in the last 12 miles of the channel, where the original longitudinal slope had been made 1 in 5,000, to reduce the velocity by the introduction of three masonry rapids. The quantity of earthwork, brickwork, and concrete required in enlarging and reconstructing the main line was very large; and the work took 3½ years to carry out, *i.e.*, from the autumn of 1892 to the spring of 1896. A great deal of it was extremely difficult, especially the foundations of the bridges, owing to the amount of water percolating from the original canal, which was kept in flow alongside and effected during this time the irrigation of 1,066,894 acres. The procedure followed is shown in *Fig. 2.* An earthen bank was left between the old and the new channel during the excavation of the latter, and was subsequently removed, so as to form a single

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channel of the dimensions already given: its removal was done partly by dredging, but principally by immense gangs of coolies during short periodical closures of the canal.

Simultaneously with the enlargement of the main line, two other divisions were formed by the construction of the Jhang and Bhawana branches, and of the distributaries in connection with them. These were opened in 1896, and at once put into use; the results were shown in the large increase in irrigation during the years 1896–98. As these two branches neared completion, work was commenced on the large Gugera Branch Upper and the Gugera Lower and Buralla Branches on the south side of the tract; these have since been completed as originally contemplated, and are now being extended so as to permit of irrigating lands bordering the River Ravi, which were not included in the original scheme.

The chief difficulty in constructing these works lay in obtaining and maintaining the immense amount of labour required in a country which produces nothing but scrub jungle, with a little grass at certain seasons of the year, snakes and lizards; even the water is, as a rule, so brackish as to be useless for drinking and unpleasant even for bathing. The first endeavour always was to push a small channel down the alignment of the branch, in which water could be run from the main canal to fill local hollows; until this was effected, all drinking-water, except where by chance there was a sweet-water well, had to be carried from the nearest canal or good well, in iron drums on camels. The water-channel once completed, life for both Europeans and natives became bearable, as shopkeepers soon followed the gangs with the few wants of the coolie or native mason.

For the construction of the works the engineer has to provide every particle of the materials, and is unable to obtain them ready made, as could be done in more civilized tracts. He must find suitable earth for brick-burning, must purchase, cut, and carry the trees for fuel, supervise the moulding and burning of the bricks, find the limestone for lime, make the charcoal to burn it, and arrange for its calcination. This is all that it seems necessary to say with regard to the actual construction of the works.

Distributing Channels.

In the alignment of the channels the first step is to find out, either by levelling or by traversing, the drainage-depressions of the country, as these form the limits of the areas

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commanded by the various branches and distributaries. Such depressions are indicated by fine lines in Fig. 1. Along the centre of them a certain width of land has been reserved from colonization, so that, if necessary, they can at any time be cleared and opened out for surface-drainage, in order to carry off any surplus water from the irrigation; they are generally only shallow depressions, often not more than 4 or 5 feet below the general level of the surrounding country.

The canal branches are aligned on the main ridges of the country, and from them take off the major distributaries which are aligned on minor watersheds. In some cases minor distributaries again take off from the majors, in order to reach outlying tracts, or to lead the water in a government channel to the boundary of a settled village. The village watercourse system takes off from either the major or the minor distributaries; rarely, for administrative reasons, from a branch or main canal direct. The arrangement of government channels is shown on the general plan (Fig. 1, Plate 4), and to a larger scale for the Rakh and Mian Ali branches in Fig. 3, Plate 4.

The design of the channels themselves calls for little remark; they are earthen channels of the usual description, bridged where necessary, and with masonry falls at intervals according to the grading and the general slope of the country. The longitudinal slope varies between 1 in 6,250 in the large channels, and 1 in 3,000, or even 1 in 2,500, in the small. The aim is to keep the velocity down to about 3 feet per second, because the soil in which the channels are made will not usually stand a much higher velocity without cutting; while a lower velocity is apt to result in a heavy deposit of silt. The amount of silt carried in the Punjab rivers in flood is very large; and the endeavour is to carry this in suspension through all the channels, and deposit it in the fields, where it acts as manure; instead of allowing it to be deposited in the channels, from which it would have to be cleared out by hand labour. Great success has attended such endeavours in recent years.

The side slopes of the canals and major distributaries are made 1½ to 1, and those of the minor distributaries 1 to 1. The banks are 20 feet to 25 feet wide on top for the main canal, and 10 feet to 20 feet on the branches, according to their capacity; one bank, however, is usually made nowhere less than 20 feet wide, in order to permit of inspection in a dog-cart during the hot weather. The top of the bank is made 3 feet above full-supply level on the main canal, and 2 feet on the branches; and this allows of greater

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depths of flow than those for which the channels were originally designed, after the earthwork has become so consolidated that a less margin is considered safe.

The banks of the distributaries vary from 10 feet to 2 feet in width at the top according to the discharge; and a margin of 2 feet to 1 foot above full supply is allowed. Some of the distributaries are of considerable size, as will be seen from the general map (Fig. 1, Plate 4), and discharge as much as 500 cubic feet per second. Instances of large distributaries are the Nasrana and the Chiniot systems; and there are several others.

Levelling and Surveying the Land.

With the watercourses in a settled village Government has little to do, except that the canal engineers are always willing to advise the villagers as to the best lines for the channels, and will, if necessary, take levels to determine them: the channels are made and maintained by the villagers themselves. But in new villages into which settlers are imported, it has been found necessary to go into much greater detail; and, as already stated, this forms the distinctive feature of the Chenab canal, and is the development of the last 6 years. Every settler, on being brought in, is practically guaranteed irrigation annually, for a certain portion of the holding allotted to him; and it became evident that in order to ensure the irrigation, the surface-levels all over the holding must be known, so that the levels of the channels might be so designed as to allow of the water flowing on to the land from them; or, if for physical reasons this proved impossible, that the land might be reserved and not allotted at all. It has therefore been found necessary to obtain the level of the ground at six or eight places on the boundary of each square, as indicated by the crosses × in *Fig. 4.* These levels can be most systematically obtained by lockspitting a perfectly straight base-line running east and west along the centre of the tract to be irrigated; and then setting off at right angles to it other lockspits at intervals corresponding with the length of the side of the squares into which it is desired to divide up the land. These cross lockspits are extended to the boundary of the crown land which is to be blocked out on either side of the base. Levels are then taken along them at intervals of half- and whole-square lengths, each point being marked on the ground by a suitable peg or pillar. The plan is illustrated by *Fig. 5.*

It was originally decided that the whole of the Crown waste land in the Rechna Doab should be divided into squares of 1,100 feet side, as that length fitted in with the local native land-

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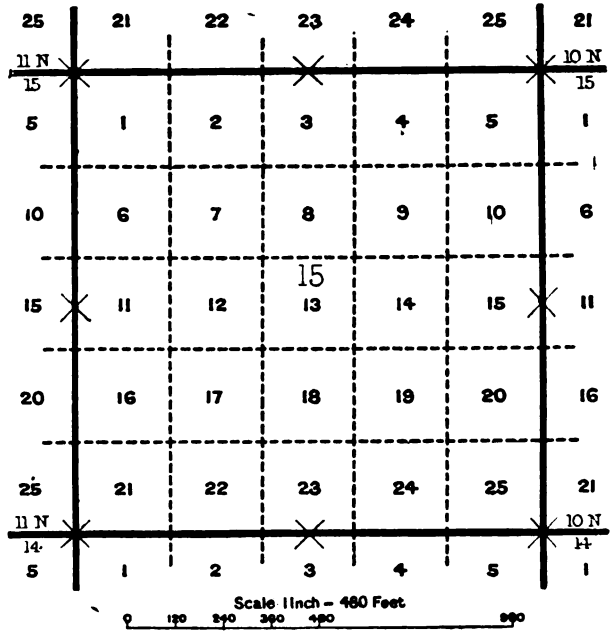
measure. The area of such a square is 27·78 acres—a somewhat inconvenient unit, which is being remedied in the last scheme designed, wherein the length of side of the squares will be made 1,045 feet, giving an area of 25·07 acres. This is more convenient, being easily divisible, by four lines parallel to the sides, into twenty-five compartments or fields, each of which, for all practical purposes, measures 1 acre. The settler is required to subdivide thus into 1-acre fields the squares of his holding, thereby immensely facilitating the registration and measurement of the irrigation, and minimizing the chance of fraud by the petty

Fig. 4.



measuring establishment. The squares into which the waste land is divided may then be represented by *Fig. 4.*

As the result of these operations, levels are obtained at about 500-foot intervals on lines 1,045 or 1,100 feet apart; and these, when plotted, enable an engineer to prepare an absolutely accurate contour map of the country. The amount of levelling done is enormous; but it has proved not only to be time and money well spent, but to be absolutely necessary. The pillars at each level point are numbered systematically, so that in these immense wastes it is possible for the engineer to know where he is immediately

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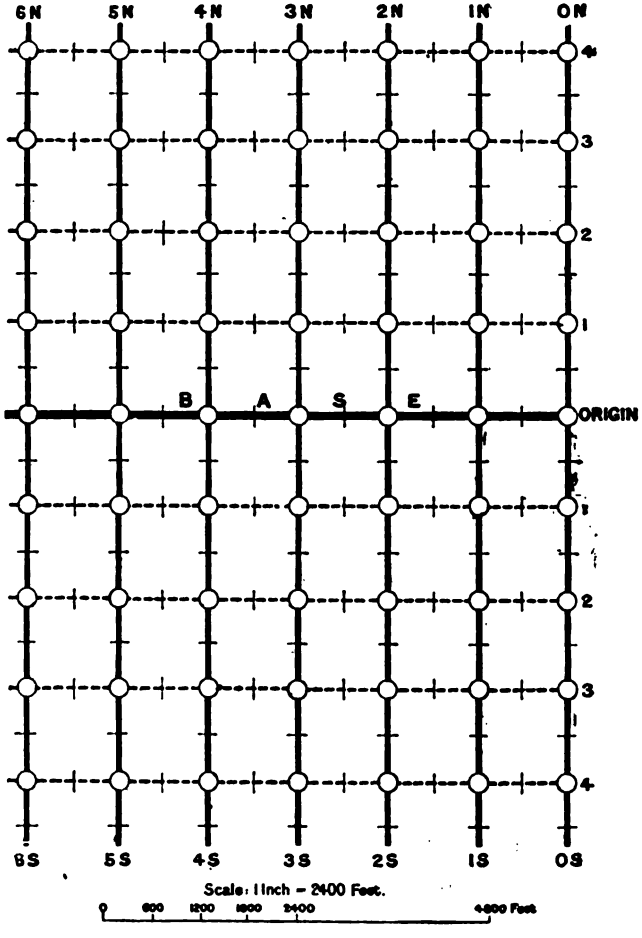
a single pillar has been found. The numbering adopted is as follows :—The first north-and-south cross line, namely, that starting from the origin of the survey, is numbered 0, the second 1, the third 2, and so on; the points forming the corners of the squares are similarly numbered, 1, 2, 3, counting north and south

Fig. 5.



from the base-line, and the addition of letter N or S shows whether the point on the cross line is on the north or south side of the base. Thus, $\frac{10\ N}{14}$ in *Fig. 4* indicates the fourteenth point on the tenth cross line from the origin on the north of the base

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line. Until the waste has been plotted out in some such manner, it is impossible for the engineers to find their way about; and many times have they lost themselves, ridden miles trying to find their tents, and sometimes had to spend the night under a tree, owing to their failure to do so; for it is rare to come across any one, of whom to enquire the way. When the north-and-south cross lines have been laid out, it is only necessary to join the points forming the corners of squares by lookspits parallel to the base, as shown in *Fig. 5*, in order to complete each square; this is done by each settler directly he comes in, and he has then no difficulty in finding the limits of his holding. The plan here described is not, of course, a scientific method of surveying; but it is a systematic method of blocking out large areas of waste land, and the irrigation maps are easily and accurately prepared by the unscientific establishment available.

Fig. 3, Plate 4, shows, to double the scale of Fig. 1, a portion of two of the canal branches, and the way in which the land is divided into villages. The latter are of different sizes, the average area aimed at being about 1,500 acres; but the limits of each village are obviously governed by physical considerations. The general principle has been not to have portions of a village on both sides of a distributary, because to do so would largely increase the number of bridges across the channel. When the whole area commanded by any distributary has been portioned out into suitable villages, the arrangement of watercourses for irrigating each square in them is designed, as illustrated by Fig. 6, which is a facsimile of the irrigation map of the Tulwala distributary area. It is divided into square blocks; and contour-lines, traced from levels obtained in the manner already described, are shown at 1-foot intervals. A channel is aligned to the highest point of every square (indicated in some of the squares of Fig. 6 by a short diagonal stroke in the corner), so that the cultivator obtains his supply to the best advantage. Any plots which are too high to be commanded for flow-irrigation by the channels as designed are not given out to colonization in the first instance, but are retained as common land for fuel and fodder reserves of the whole community of the village. Several such plots are indicated in Fig. 6. As the demand for land becomes greater, some of the high ground will probably be allotted; for lift-irrigation, or a future regrading of some of the channels when the earthwork has become consolidated, may so raise the level of the water as to bring portions of the high land under flow-irrigation.

This completes the irrigation system of the Chenab Canal. Each channel of this gigantic system, from the main canal itself to

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the smallest watercourse, has to be specially designed; its capacity has to be calculated throughout its entire length, according to the area to be irrigated below any given point; its section and the slopes of its bed have to be determined, as well as the size of each individual outlet from the distributaries, so that the distribution of the water may be equitable. The outlets or sluices serving the watercourses are usually rectangular in section, and of sizes varying with the discharge required and the velocity through them. The velocity is calculated roughly from the head, *i.e.*, the difference in level between the water-surfaces of full supply in the distributary and in the watercourse; the volume allotted to the outlet and the velocity of discharge being known, the area is at once obtained. In practice a certain number of sizes have been designed, and the nearest to that required by calculation is selected and built. The volume allotted to an outlet depends on the area commanded by it, and on the allowance per square mile for the particular tract in which it is situated.

Subsidiary Work.

Besides the canal itself, the irrigation engineers have carried out an immense amount of work in connection with the new towns and communications in the colony. Roads have been constructed along both boundaries of every Government channel (Fig. 6); and these, with certain main district roads, form the leading thoroughfares of the country. Further, in conjunction with the watercourses, a number of inter- and intra-village roads are constructed; the former are necessary to permit of the villagers getting from village to village, or to the main lines of communication leading to the railway and markets; and the latter to allow of each man getting from the village to his holding without traversing his neighbours' fields. Only the former are indicated on the plan, Fig. 6, which would be too confused if the latter were also included. All these roads, and the thousands of culverts to pass the watercourses under them, are constructed by the canal engineers at the same time as the channels themselves.

At an early stage it was seen that a railway running through the centre of the tract was an absolute necessity. The first 96 miles of the line, from Wazirabad to Lyallpur, shown in Fig. 1, Plate 4, with the exception of the girder-erection and platelaying, were constructed by the canal engineers, as the Railway Department was unable at the time to supply men; but the continuation to Multan was subsequently built by the department.

Up to the 31st March, 1901, a total area of 1,466,125 acres of Crown

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land had been allotted; while the census taken in that month showed that close on 800,000 persons had been imported into the area. Several towns of considerable size have been built. Lyallpur, besides being a town of 8,000 to 10,000 native inhabitants, is also the headquarters of the canal, and of the civil district; and a large civil station has been built mainly by the canal engineers.

Administration.

The introduction of the settlers is in the hands of a special civil officer, and the engineers have practically nothing to do with it; interesting as the subject might be, it is therefore outside the scope of this Paper. The main point that will be of interest to the members of the Institution of Civil Engineers is, that the whole of the administration and the assessment of the revenue, as well as the construction and maintenance of the canal, is in the hands of the engineers, who have under their orders a suitable native staff for the purpose.

There has at times been much controversy on this subject. Many of the civil revenue authorities contend that the assessment work, being more in their province, could be better done by them; and that it is not right that the assessment should be in the hands of the officers of the department directly interested in showing large profits from their own works. On the other hand, it has been urged by the engineers that it is imperative, for the efficient and economical distribution of the water—which for many reasons must be in the hands of those responsible for the maintenance of the canals—that they should know exactly where the water is going, and what duty it is doing; and that they can obtain this knowledge only if the fields irrigated are registered under their orders. Moreover, it is argued that it is to the advantage of both the canal administration and the cultivator that the engineer, who alone can redress any grievances caused by faulty distribution, should be brought into intimate and direct communication with the cultivators. Various other reasons of minor importance have been given; but the above are the principal, which have induced the Government to leave the administration and assessment in the hands of the engineers, and gradually to transfer to them the similar work on many old and small canals, that were previously in the hands of the revenue officials.

Thus administration forms a most important and trying portion of the canal engineer's work. It is trying, because in all seasons of the year—hot weather, rains, or cold weather—he must be on tour throughout his charge, to see that the large staff of native petty officials are doing their work honestly, both to Govern-

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ment and to the cultivator. In a year of scanty or deficient rainfall the canal watercourse is the saving of the country, and the cultivators are only too ready to offer bribes in order to obtain a watering out of turn. This is an immense temptation to the native official, who regards such practices as venial. As, however, the water is all allotted to the various channels by the senior responsible engineer on a regular roster, it is obvious that, if some cultivators obtain a watering out of turn, they do so at the expense of others, whose crops may wither in consequence. This portion of the engineer's duty is rendered more arduous in bad seasons when the rains fail, and famine or scarcity stares the people in the face. The effect of such failure is not only to render the climate in the plains more unbearable than usual to the European, but also to send up prices, inducing the cultivator to sow as large an area as possible, in the hope of netting a considerable sum. At the same time it reduces the volume in the river from which the canal is fed, and consequently the amount of water at the disposal of the engineers. The cultivator's need of liberal and timely waterings is therefore more pressing, and consequently he is the more ready to increase the amount and frequency of his bribes in order to obtain them.

The work of a railway engineer, except in the few instances of training-works on large rivers in connection with the bridges crossing them, practically does not extend beyond the boundary fence of the railway; and a large amount of inspection can be done from a carriage or trolley. Of the irrigation engineer, however, it is almost correct to say that his work, whether of construction or administration, only commences at the boundary of the canal; for it leads him into every field into which the immense area is divided, and can only be done slowly by riding on horseback.

The whole system is divided into a certain number of divisions in charge of executive or resident engineers; and each division contains two to four subdivisions, each in charge of an assistant engineer. The superintending engineer of the canal fixes the volume of water to be passed into each of the main branches, and the period for which it is to remain in flow, according to the indents of the divisional officers and the total volume available from the river. When the supply in the river is in excess of the full supply of the canal, this is a comparatively easy matter. If the demand warrants it, the canal is then allowed to run full, which, in turn, gives full supplies to all the branches and distributaries. The difficulty really begins when the supply falls

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below the requirements; and it is then that the energies and intelligence of the canal staff are taxed, in order to ensure a fair distribution and to mature as large an area as possible. This occurs in the cold weather.

The Chenab River usually remains fairly full until the middle or end of October, thus giving ample supply for cold-weather sowings. Should the cold-weather rains fail, the crop will be entirely dependent on the canal, while the total discharge of the river will probably not exceed 4,000 cubic feet per second. If the water were available, it is probable the canal would be kept running full more or less steadily; but the necessary volume not being available, the whole volume in the river is passed into the canal, and distributed to the different branches in rotation.

Some years ago the system followed was to distribute the water among all the branches, supplying each steadily with its due share of the quantity available. But on this plan the distributaries could not run full, with the result that lands which were high did not receive water, because the depth in the channel was not sufficient to cause flow on to them. The water was drawn off by outlets serving low lands in the middle reaches of the distributaries, and little or none reached the end; so that there was heavy failure of crops in the tail villages. This has now been altered, by making the necessary reduction in time instead of in volume. Thus every distributary, when open at all, is running full, so that all the outlets from it work fairly and as designed, and the tail villages obtain as good a supply as those at the head. When any distributary has received full supply for its allotted time, it is entirely closed, and the water passes into others. The art of good administration lies in correctly fixing the periods for which each distributary is open, so as to utilize the available supply to the best advantage, and to take advantage of any freshets which may come down the river, owing to rainfall in the catchment-area of the river above the weir.

Thus, the distribution must be so arranged that, if to-day 4,000 cubic feet per second are being received, to-morrow 8,000 or even 10,000 cubic feet per second can be distributed, if such larger volume reaches the canal head. In order to do this, it has been found necessary to have a private telegraph line extending all over the country irrigated, in order that every officer and subordinate may be informed at once what volume is available and which channels are to be opened. The new plan has also the enormous advantage of economizing water, as the shortest length of channel is kept wet, and consequently the loss by absorption and evaporation is

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reduced to a minimum. The divisional officer, having been informed as to the volumes and periods of flow fixed for each branch, then decides the distributaries which are to flow simultaneously in order to utilize the supply, and the periods for which they are to flow. The period depends largely on the crops which have been sown, rice and sugar-cane requiring heavier and more frequent waterings than cotton or the millets. The divisional officer's orders are telegraphed to every subordinate concerned.

Coming now to the cultivators, it has already been said that the watercourses, which take off from the distributaries, are in their charge; and they are at liberty to open the sluices whenever there is water flowing past them, unless for any reason a special order for closure has been given. The distribution of the supply in the watercourse among the cultivators dependent thereon is done in accordance with a share-list, that gives each man the right to use the whole supply for a certain period, during which he may irrigate as much land as he can. If in the time at his disposal he has been unable to water the whole of the area he has under cultivation, the area unwatered must wait until his turn comes round again in 15, 21, or possibly 30 days' time. The period during which each man has the use of the water is usually a multiple of 4 hours, so that a man may get water for 4, 8, or 12 hours. Sometimes a watercourse is so large that it discharges too great a volume for any one man to deal with: in that case the total area commanded is divided into blocks, each of which is served by a branch of the main watercourse; and the system described above is then applied to each branch watercourse. The cultivators know exactly when each man's turn is up; and in times of short supply and keen demand, the next shareholder will be waiting ready with his spade to take over the watercourse, and divert the water on to his own land, directly the turn of his predecessor is up. Needless to say, disputes are not infrequent, and have to be adjudicated on by the canal officers, who, under a special Canal Act, are given magisterial powers to dispose of them legally.

For the registration of the irrigation, the revenue officers, in making the land settlement of the country, have prepared detailed maps, called in the vernacular "shizrahs," showing the configuration of each field. The fields are numbered serially for each village; and besides being recorded on the map, they are entered in a book called a "Khasrah," which gives full information regarding the owner, occupancy or cultivating tenant (if any), area, soil, etc. Copies of these maps and registers are supplied

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to the canal establishment; and as each field is irrigated, a record of the number, date of irrigation, and crops sown, is entered in a special register. Such registration is carried on continuously during the currency of the crop, as fast as fresh fields are irrigated; and one of the chief duties of the assistant engineer is to see that it is correctly and regularly done, so that fields which have received one or two waterings may not escape assessment at the end of the crop, in case favourable rain should render late waterings unnecessary, and possibly obliterate the signs of previous canal irrigation. Later in the crop, the area actually irrigated is measured, and a slip or bill is given to the cultivator, intimating the amount of assessment for which he is liable. Where the whole of a field has been irrigated, the official area recorded in the "Khasrah" is taken, and no actual measurement is made; but if the field is large, and a portion only has been irrigated, or if two crops falling in different classes of the schedule of water-rates have been sown, actual measurement with the chain is made. As the schedule of rates is fixed on the acre as the unit, the convenience of having the squares in the new colony divided into twenty-five fields, each of which practically measures an acre, will be appreciated at once.

When all the fields in a village have been measured, a demand statement is prepared and forwarded to the chief civil officer of the district, who causes recovery to be made through his own subordinates and the amounts to be paid into the Treasury, to the credit of the Canal Department. For the actual recovery of the money the engineers have no responsibility, other than to see that the gross demands are eventually brought to the credit of the Department. It is evident that there are sure to be many objections raised against the demand. These usually fall under one of the following heads:—

(i) That the field was not irrigated from the canal at all.
(ii) That the area irrigated has not been correctly measured.
(iii) That the crop matured has not been correctly classed.
(iv) That the irrigation was by lift, and not by flow as charged.
(v) That the demand, although correct, has been made upon the wrong person.

Complaints on any of the above points may be made in writing by the person against whom the demand has been formulated, and must be investigated and decided, often on the spot, by the Executive Engineer or his assistant. Needless to say, many of the complaints are frivolous, and are put forward for the chance of obtaining some remission; often they are instigated by the native

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petty establishment. Some are just, and the errors thus brought to light are corrected by the issue of revised demand statements to the civil officer. All the assessment work and the correspondence arising therefrom are carried out in the vernacular, because none of the cultivators who present petitions, and few of the petty officials who have to report on them and prepare the demand statements, understand English, although knowledge of that language has extended greatly during the last 20 years. It is therefore imperative that the canal engineer should be proficient in the native language, and, it may be added, in close sympathy with the cultivator and at all times accessible to him.

Many engineers may think that all this work is outside the province of a scientifically-trained man; and it is perhaps well that the Author should show why he strongly holds a different opinion. One great object of the canal engineer is to get as good a duty from the water as possible, *i.e.*, to mature the crops with the least possible volume: for not only does he thus earn the best return for the canal, but he saves the land from the evil of over-saturation. The usual method of estimating the duty is by the number of acres of crop which can be matured by 1 cubic foot of water per second, running continuously. A fair duty is 100 acres of crop per cubic foot per second (of the average supply entering the canal at the head) in the rains, and 200 acres in the cold weather. This is what is aimed at, and often obtained: it means that 1 cubic foot per second running continuously into the canal-head will mature 100 acres in the rains crop, and 200 acres in the cold weather, making 300 acres in the year.

The duty of the supply entering at the canal-head is that which the superintending engineer would apply in reviewing or criticizing the working of the whole canal, and comparing its efficiency with that of other canals in the Province. But it is necessary that the executive and assistant engineers should compare the working of individual distributaries, in order to see which are working badly and which economically, so that investigation regarding the former may be made at once. If the recording of the irrigation were not in the hands of the engineer, he would not obtain the information on which his deductions must be based, until it was too late to remedy the evil. A keen assistant works out the duty of each of the channels in his charge at least once a month, and institutes immediate enquiry into the cause of any working badly. It will often be found to be due to a channel having been allowed periods of flow that are excessive for the irrigation dependent on it, so that the crops have

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been obtaining an undue share of the volume available; and this being detected can be remedied during the remainder of the crop. Perhaps the most suitable method of stating the duty of distributaries is in terms of the depth of water poured upon the land, for this appeals to the unscientific native establishment quite as much as to the engineer; and it is important that they too should be induced to take a keen interest in the working of their channel, and to vie with each other in showing the best results. This method is therefore now generally adopted. In order to determine the duty, it is necessary to know the volume entering the distributary, and, no module being yet available, it has to be estimated by forming curves of discharge for each channel, which curves are frequently changing owing to the deposition of silt, or to its removal at different seasons of the year. The observations and calculations can be made only by someone trained with the care and exactitude of an engineer; and the Author is confident that the efficiency of the canals in Upper India is largely due to the attention which has been given to this subject in recent years.

In the foregoing general sketch of the heavy duty and responsibility of the engineers in charge of a modern irrigation-canal in the Punjab, nothing has been said of their anxiety. Imagine a series of channels discharging close on 11,000 cubic feet per second in the fierce heat of June or July, when every drop of water is greedily utilized; the rains break suddenly, and the engineer has to determine what is to be done. To continue the channels in flow may cause numerous breaches, damaging large areas of crops, villages, or towns; to reduce the supply may cause the withering of crops in tracts which have received no rain, for the area commanded by the canal is 160 miles long by 60 miles broad, and the rain may not extend over the whole of it. He must then exercise his discretion, and will probably order a partial reduction of the supply, while he obtains telegraphic information from all the outlying tracts as to the extent of the rainfall. It is here that the telegraph is so useful; and only those who, like the Author, have had to regulate these large canals before its use became general, can appreciate the anxiety experienced by the responsible officer.

In this connection it may be pointed out that large escapes back into the rivers are impossible, especially towards the ends of the branches, where they would be most useful; for every channel must taper down so that the capacity at every point may correspond with what is necessary for the irrigation of the area below that point. High up in the canal a large escape is of little use because it is almost as quick to reduce the supply entering at

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the head. On the general plan (Fig. 1, Plate 4) will be seen seven areas marked "R." They indicate hollows or depressions in the ground, surrounded by earthen banks, so as to form reservoirs, into which a portion of the supply can be turned, in order to relieve the strain on the canals during periods of sudden cessation of the demand, until a reduction at the head ordered by telegraph can take effect. It is obvious, however, that they can be only sparingly used, and must be kept as empty as possible, otherwise they will be useless when most wanted.

Results realized by the Chenab Canal.

Any such scheme as has been outlined in this Paper will naturally be judged by its results; and it will therefore be of interest to record what the Chenab Canal did up to the 31st March, 1901, the end of the last official year for which statistics are at present available; those for 1901–1902, when published, will be even more favourable.

The total capital expenditure amounted to Rs.252,63,656, equivalent to £1,684,243 14*s.* 8*d.* at the present rate of exchange of 1*s.* 4*d.* per rupee. It was divided as follows:—

	Rupees.
Cost of works	205,14,955
„ „ establishment	37,75,694
„ „ plant	5,96,482
Value of stock in hand and miscellaneous advances	3,90,928
Total . . .	252,78,059
Less receipt on capital account	14,403
Net total . .	Rs.252,63,656

The works comprised, at the 31st March, 1901:—

1. A weir across the River Chenab, with many miles of training works.

2. Main canal 40 miles in length, with a capacity of 10,800 cubic feet per second.

3. Branch canals, 390 miles.

4. Distributaries, 2,095 miles.

5. Upwards of 100 inspection-houses for officers, subordinates, and their servants. Some of these are indicated on the general plan.

The area of land commanded by the canal was 2,910,470 acres, of which 2,645,992 acres are cultivable.

The cost has therefore been Rs.8·68 (11*s.* 7*d.*) per acre of gross

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land, and Rs.9·55 (12*s.* 8¾*d.*) per acre of cultivable. The cost of the establishment has been 18·4 per cent. of the cost of the works.

The total area irrigated has amounted to 6,722,621 acres. It is still developing, as will be seen from the following figures, and is yet far from having reached its ultimate limits:—

1889–90	. . . . .	39,300	acres irrigated
1890–91	. . . . .	52,390	„ „
1891–92	. . . . .	35,524	„ „
1892–93	. . . . .	157,197	„ „
1893–94	. . . . .	270,405	„ „
1894–95	. . . . .	269,857	„ „
1895–96	. . . . .	369,935	„ „
1896–97	. . . . .	520,279	„ „
1897–98	. . . . .	810,000	„ „
1898–99	. . . . .	957,705	„ „
1899–1900	. . . . .	1,353,223	„ „
1900–1901	. . . . .	1,828,800	„ „

In the year 1901–1902 the area irrigated further increased to 1,957,700 acres; and the Author confidently anticipates that when another Rs.20,00,000 to Rs.30,00,000 (£133,333 to £200,000), has been spent upon it, the Chenab canal alone will mature 2,500,000 acres of crops annually, in a tract of country where the annual rainfall, on the average of the past 11 years, has amounted to only 11·81 inches.

In some tracts the irrigation has been excessive, and the subsoil-water is already rising: so that, in extending the irrigation to the tracts nearer the river, arrangements have been made for a more or less automatic reduction of the supply as the subsoil-water rises, with a view to prevent the evil of over-irrigation and consequent water-logging of the soil. In the high lands in the centre of the tract, there is little chance of this being an evil for many years to come, because the spring-level is still 80 to 90 feet below the ground, which can easily be drained, owing to the reservation of the drainage-lines by Government. But in the lands bordering the river it is far from being so, and great watchfulness will be necessary, in order to prevent the cultivators, in their eagerness to become rich, from spoiling the land for their descendants. The proposal which has been approved is that, while the spring-level is more than 40 feet below the surface, water may be given for the irrigation of 50 per cent. of the culturable area in the year; but, as the water-level rises, the percentage of the total area for which water will be given will be reduced; and when the spring-level is 10 to 15 feet below the surface, the supply will be withdrawn altogether, or given only

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for one crop in the year. Giving irrigation for the hot-weather crop only will assimilate the conditions to those of the inundation canals. An inundation canal, as already stated, is not combined with a weir across the river, and consequently can obtain a supply of water only when the river rises by the melting of the snows in the high Himalayas, or when it is in flood during the annual monsoon. As the river falls at the end of the rains, these canals run dry; and the cold-weather crops, which have been sown by the aid of canal-water, are matured by the aid of wells. Not only, therefore, is there a cessation in the continuous pouring of fresh water on the land, but the subsoil water-level is lowered by water being drawn from numerous wells during 6 months of the year.

The investment is highly profitable to Government as well as to the people. In 1900–1901 the net revenue assessed gave a return of 18·18 per cent. on the capital; but this is after allowing large remissions to the settlers in the early years of their tenancy; and it has been calculated that, if the area actually watered had been assessed at the full rates (which are coming into force by degrees), the net revenue, after deducting working-expenses, would have yielded a return of 24·58 per cent.

Since the canal was opened, the total receipts have amounted to Rs.180,76,041, and the working-expenses to Rs.63,22,118, leaving a net profit of Rs.117,53,923; deducting the charges for interest during construction at 4 per cent., amounting to Rs.74,48,080, there remains a balance of profit, after paying all charges of interest on loan and working-expenses, of Rs.43,05,843: equal to £287,056 4*s.* 0*d.*

Water-Rates.

The schedule of water-rates is given below. The various crops grown are divided into classes, roughly according to the quantity of water they require and the general value of the produce. There are six classes, as follows:—

Class.	Crops.	Water-Rate per Acre.					
		Rs.	An.	Pie.	£.	*s.*	*d.*
1	Sugar-cane	7	8	0	0	10	0
2	Rice	6	4	0	0	8	4
3	Orchards, gardens, tobacco, indigo, vegetables, poppy, melons, coriander, cumin and aniseed	5	0	0	0	6	8
4	Cotton, fibres, dyes (except indigo), oil-seeds, Indian corn, and all cold-weather crops except grain and lentils	3	12	0	0	5	0
5	All hot-weather crops other than those specified above	2	8	0	0	3	4
6	Single watering to plough, not followed by a crop	1	4	0	0	1	8

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The foregoing are the rates for irrigation by flow; lift rates are half these figures. Besides the direct water-rates, there are three other small rates amounting to 1 rupee 4 annas (1*s.* 8*d.*) per acre, which are levied on the area irrigated, irrespective of the crop grown; the receipts from these are credited to various accounts of the general administration.

The Paper is accompanied by drawings from which Plate 4 and the Figures in the text have been prepared.

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Discussion.

The PRESIDENT remarked that the Papers showed the extreme value of the irrigation work carried out by English engineers abroad, and also called attention to the important administrative duties which they were called upon to undertake, quite apart from ordinary engineering work. He had great pleasure in proposing a vote of thanks to the Authors for their Papers. The President.

Mr. R. B. BUCKLEY thought that those members who were acquainted with Egyptian irrigation would be struck with the great similarity between the Bhadar weir and the Asyut and Zifteh weirs, which had just been completed. But there was one important difference between them, namely, in the shutters. He did not quite understand the arrangement for working the shutters of the Bhadar weir when the floods came, but he presumed the beam on which the upright channel bars rested was removed. He ventured to think the form of shutter described in the Paper was not a suitable one. It was somewhat like the shutters used in some weirs in France, but it was a form which would give rise to a good many difficulties when floods came, and the whole of the shutters had to be cut adrift in the stream. In India, notably on the Sone weir and in Orissa, forms of tumbling shutters had been used in somewhat similar situations, namely, in the under-sluices of the weirs; and there were many situations in which such shutters, which had been described in Papers[1] read before the Institution, were very useful. But the forms of shutter which had been adopted on the Chenab weir in Upper India, and particularly on the weirs in Egypt to which he had referred, had, he believed, superseded those which had been adopted in Bengal, and he thought they were far better than those described in Mr. Benson's Paper. They were plain iron shutters spanning the entire opening, about 3 to 4 feet high, and they were lifted by one, two or three travellers, as the case might be, which traversed the whole length of the weir. They could easily be removed when the occasion demanded, and were extremely simple to work. It would have been better if the plan had been adopted which had now been approved for India, and largely adopted in Egypt. Mr. Buckley.

[1] Minutes of Proceedings Inst. C.E., vol. lx., pp. 24 and 43.

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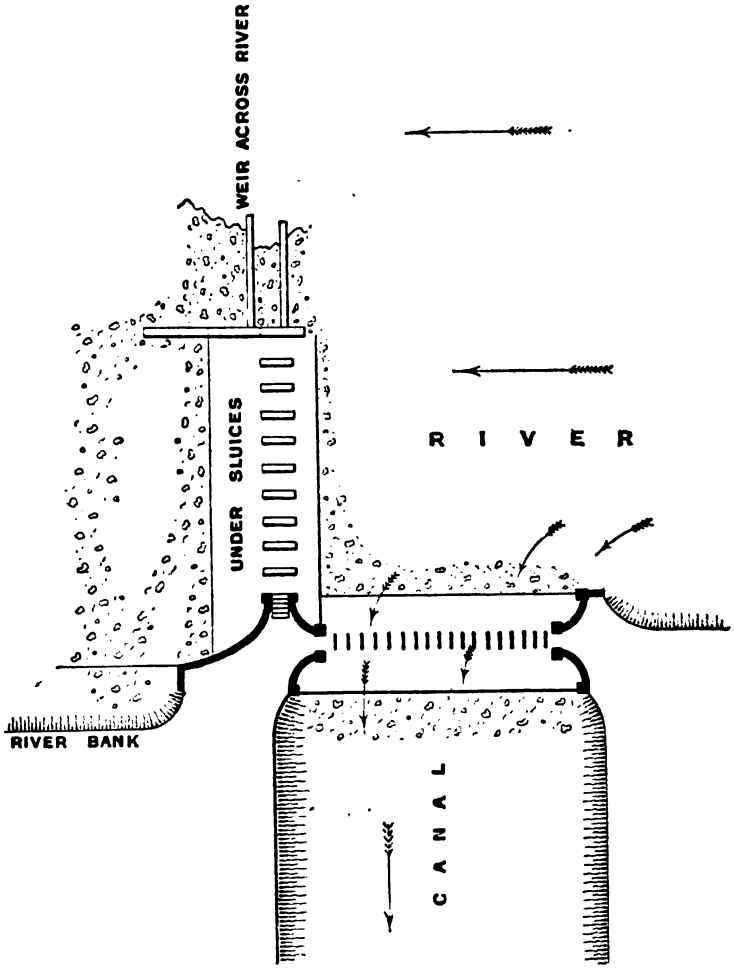
Mr. Buckley. He wished to corroborate Mr. Preston's remarks upon Kutter's formula. It was generally the practice to take N in Kutter's formula for canals as 0·025; but in many canals—notably those

Fig. 1.



which had silted to a certain extent, and therefore had adjusted themselves into the best form of channel—a much higher discharge could be obtained than was indicated by the formula; an increase of 20 per cent. or even 25 per cent. having been obtained in cases

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within his knowledge. With regard to silt, all canal engineers knew the great difficulties caused by silt in the canal-head. In the last 10 or 15 years there had been a notable advance in India towards overcoming those difficulties. In some canals the water flowing in from the river caused large deposits, which tended to reduce materially the discharge of the canal, sometimes at critical periods, and necessitated the removal of the silt by fleets of dredgers, at heavy expense. In the Sirhind and Sone canals both expense and difficulty had been entirely obviated by a few simple expedients. The primary use of under-sluices in a weir across a river was to maintain in the river a channel leading to the head-sluice of the canal (*Fig. 1*). In many cases it was thought to be the right practice to keep open as many as possible of the under-sluices, in order to induce scour in front of the head-sluice. No doubt the result was that a channel was kept open; but it had been found that, where the river-bed was of sand, the high velocity which was induced kept the river-bed in front of the head-sluice in a constant state of agitation, and the sand from the bed was caught up by the draught of the head-sluice vents and drawn into the canal, where it was immediately deposited, because the velocity was materially reduced as soon as the water got fairly into the canal. This was especially the case when only a few of the head-sluice vents were open, and the head on them was considerable. There were five main points which experience showed should be observed, in order to reduce the deposition of silt at the head of a canal. The first was to reduce the velocity in the river in front of the canal head-sluice, by keeping the under-sluices next to the canal closed as far as possible, the result of which was that the sand on the bed was not churned up and carried into the canal. Of course when floods came down that could not be done; the under-sluices were opened, or opened automatically, and a high velocity was induced. The head-sluices of the canal were then closed altogether. The second point in connection with the reduction of silt was to draw the water, as far as possible, from the surface of the stream, instead of from the bottom of it, as had been practised at first. That was done, not because the top water of the river had less silt in it than the bottom water, although that was true to a certain extent, but because, by drawing the water from a narrow layer at the top, the disturbance of the water in front of the sluices was stopped, and consequently the churning action which went on did not stir up the bed of the river and carry it into the canal. The deposit which had formerly occurred at the head of the Sone canals had been largely sand from the bed of the stream. It was desirable to reduce the

Mr. Buckley.

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Mr. Buckley. velocity through the sluices by increasing the water-way, and especially by drawing the water from the top in as shallow a layer as possible, so that the velocity of approach to the head-sluice was as small as it could reasonably be made. The third point was to keep the largest possible flow in the canal, even during the period when the quantity of silt in the river was at a maximum. This might seem to be the reverse of what was desired. But by keeping as large a flow as possible in the canal during the season of silt, the canal would be caused to maintain its section, and the silt would be forced forward on to the fields, where it was required, instead of being allowed to settle in the canal. Of course this could be done only where the sand of the river-bed had been prevented, by the means already mentioned, from entering the canal. The fourth point was the scouring of the canal after the silt season, that was, when the floods in the river had gone down, and the under-sluices were all closed. At that time the water was clear, there was little or no head on the head-sluices of the canal, and the velocity through them was small. It was then possible to open all the sluices down to the bottom: there was no object in taking water from the top, because the water was clear and did not scour, owing to the lower level of the river. During the cold weather the canals had been run to their maximum capacity, in order to keep up a large discharge and carry away the silt; and in that way, in the Sirhind Canal in the Punjab and the Sone Canal in Bengal, enormous quantities of silt had been cleared away and passed forward to the fields or flushed out of escapes. The fifth point was that, in designing new works, one of the most important things was to keep the velocity at the head of the canal as high as possible. Mr. Preston said the velocity should not be above 3 feet per second, otherwise the banks would be scoured away: but in some cases it was better to scour the banks and go to the expense of protecting them by revetments, in order to keep up a higher velocity and thus carry forward the silt. In two important canal systems the five main principles he had mentioned had been quite successful, not only in reducing the working-expenses to a large extent, but also, what was far more important, in ensuring a full supply to the canals for irrigation.

Sir Alexander Binnie. Sir ALEXANDER BINNIE, Vice-President, remarked that the Papers might be considered as, in some measure, a contribution to the knowledge of that great problem—he might almost say miracle—of modern government, by which 200,000 Europeans governed 200 millions of Asiatics. It was by the perusal of such Papers that the important part which the engineering profession was

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playing, in the endeavour to govern probably the largest number of people that had been brought under one rule since the time of the Roman Empire, was made clear. The Papers described works which in India would be considered as of no extraordinary magnitude; yet by means of the works described in Mr. Preston's Paper alone, an area of 3,000,000 acres was being brought under cultivation: which meant that an area almost as large as Yorkshire was being raised from a state of utter barrenness to one of luxuriant vegetation. Not only was that the case, but the redundant populations of certain provinces were being afforded an outlet for their labour in the profitable cultivation of an area which previously had been a desert. Looking at those facts from the broad point of view of the province which the engineer in India assumed, of not merely constructing works, but also adding to the civilization and the prosperity of hundreds of thousands of persons, the miracle of Indian government could be appreciated in some small measure. All who had ever served in that country had come away feeling in their inmost hearts that the government was beneficent to the people of the country and to themselves; and it would always remain a difficult thing to explain how and why it had been brought about. The Papers gave some slight inkling of the movements that were at work in securing that good result. From them it was seen that the engineer was not concerned only in the construction of works for bringing under cultivation large barren areas, but that he became the administrator, under Government, of the works which he had himself constructed; and, as Mr. Preston carefully pointed out, it was only by the employment in that capacity of one scientifically trained in the art of distributing water, that a profitable revenue could be realized from the large capital expenditure entailed by works of the kind. It would be a pleasant thing for all engineers if the works constructed in England were managed at a charge of 18·4 per cent. of the receipts for working-expenses, and returned to investors something like 24 per cent. on the capital outlay. When the meaning of those figures in regard to the prosperity of India and its vast population under English sway was realized, it could be understood in a small measure how it was that that population was contented under British dominion.

Sir Alexander Binnie.

Colonel S. L. JACOB thought Mr. Preston might have dwelt even more strongly on the extremely arduous duties of the canal engineer. The assistant engineer was usually the only European in the part of the country in which he lived, so that he had to forgo all the pleasures of ordinary society. Even when he was promoted, and

Colonel Jacob.

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Colonel Jacob. became a divisional officer, having his headquarters in a station with a few Europeans, he had to spend the greater part of his time—hot weather, cold weather, rain or fine—in camp, performing unceasingly harassing duties. He had to work at all hours of the day or night, as well as to eat indifferent food and drink bad water, and equally bad milk. But the canal engineer not only had the ordinary engineering work connected with the canal to perform, he had, as stated in the Paper, to carry out the whole of the administration. For that purpose he must be thoroughly acquainted with the language; not only with the language proper, but even with the dialects of the people, so that he could talk on terms of intimacy with the ordinary people of the villages, and thus get "behind the scenes." The worst difficulty that every administrator in India had to face was the extremely corrupt character of the ordinary native establishment; and it was only a really efficient man, whose knowledge of the native enabled him to get behind the scenes, who could keep down the corruption. If an inefficient man was in charge, corrupt practices flourished; such a man might spend 20 or 30 years in India and never know what had been going on under his nose. Again, the engineer had to keep the canal running at all costs, for the life of the country was dependent upon it. If such a canal as the Chenab Canal was closed for 2 months, or even a shorter period, everybody would have to leave the land as quickly as possible; because not only would it be impossible to obtain a harvest, but no water would be available for drinking purposes, the canal being the sole source of supply. The engineer might see his masonry works being scoured, and his bridges likely to tumble down, but the canal must run by hook or by crook. The destruction of half a dozen bridges might mean a matter of £10,000 at most. But a closure of the canal for 3 days to enable urgent temporary repairs to be done might cost £30,000 direct loss, and £300,000 actual loss to the cultivation of the harvest. An appalling state of things would arise if, from any dire calamity, the canal ceased to work. Undoubtedly such a thing had happened in the past, because ruins of old cities were to be met with all over the Rechna Doab country. When aligning the Chenab Canal, on which he had been engaged before Mr. Preston's time, he had found running beside his line the traces of an old canal made years before. That canal had rendered the country fertile, but it had passed away, and with it, of course, the population. Canal engineers had exceedingly onerous duties to perform, and they had been instrumental in bringing in a large revenue to the Government. The Chenab Canal, which was unique in many

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ways, produced a larger revenue than most canals, but all canals, in the Punjab at all events, paid excellently. The Chenab Canal produced a profit of about 25 per cent. per annum on a low assessment; if the Government desired, it could increase the assessment with the greatest ease, but it preferred to charge low rates. Further, the land, instead of being given to the settlers, might have been sold to them, in which case double the cost of the canal would have been realized. But Government, very wisely, did not want to do that. In view, however, of the magnificent results obtained by the canal engineers, he wished the Government would take up the matter of the canal establishment in a much more thorough way than it had done; for there was no doubt that the engineering establishment was not in a satisfactory condition. Such remuneration ought to be given as would allow of the best men being obtained. It would pay the Government over and over again; for a good engineer would earn his pay fifty times over, while a bad one would cause loss fifty times greater than his pay. Colonel Jacob.

Colonel JOHN W. OTTLEY remarked that his only excuse for speaking was his intimate acquaintance with the Chenab Canal project, of which he had laid down the first centre line in 1882. For the greater part of 12 years he had been closely associated with it, either as Superintendent or as Chief Engineer of the Punjab. Mr. Preston stated that already nearly 2,000,000 acres had been irrigated, and confidently expected the figure would soon reach 2,500,000 acres. Those were large figures, and difficult to grasp; and they might be brought home better if he gave an idea of what they meant. Recently, in connection with the food-supply enquiry, it had been stated that the whole of the home-grown wheat amounted to 6,000,000 quarters per annum. Taking the canal as it stood, and after allowing ample margin for crops such as rice, sugar-cane, cotton, maize, rape-seed, millets, etc., he found that the district irrigated by the Chenab Canal ought to be able to produce annually quite five-sixths of the amount produced by the whole of England in the year. That fact gave an idea of the magnitude of the project under discussion. On his first visit to the tract of the Chenab River, 21 years ago, it had been an interminable waste, with scarcely a living thing throughout it. There had been no villages, and the engineer had travelled sometimes many miles without seeing a human being. The subsoil-water had been at a depth of 70 feet to 110 feet, and probably more in places; the rainfall of the district was exceedingly small, and the revenue of the country, so far as he could ascertain it, had not been more than 1*d.* per acre, drawn from grazing-dues levied from men Colonel Ottley

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Colonel Ottley. who fed their camels on the thorns in the desert, or from the cattle-owners who, after a shower of rain, took their cattle there for fodder. Since 1892, the whole aspect of the place had been changed. Villages were now dotted all over the country, the population being about 140 to 150 per square mile. The Rechna Doab, instead of being a desert was now a garden; the revenue had probably been increased fifty-fold; and the railway was, he believed, earning a good return. The whole of that transformation was due to the application of water to land which was fertile in itself, and simply waited for the water to turn everything into gold. Seeing the magnificent results which had been achieved by the Chenab Canal, as constructed, it might seem a little out of place to enquire whether something better could not have been done. He was inclined to think that, with the knowledge now possessed, it might have been improved upon. The tract irrigated was really only about half the land comprised between the Ravi and Chenab Rivers, the total area of which was about 12,300 square miles. The area commanded by the present canal was about 6,000 square miles; but much of it was land which, owing to the height of the spring-level, it was not desirable to irrigate; and therefore the actual irrigable area had been put down at 4,000 square miles or 2,500,000 acres. Mr. Preston stated that in the near future 2,500,000 acres would be watered each year; that meant that every acre of the tract would be watered every year. He thought all irrigation officers would agree that that was a mistake, and that if possible more land ought to be under control. The only way to get more land would have been to go to the head, where the water came from the hills, and to command the whole tract of 12,000 miles. That scheme had been thought of long before. As far back as 1862 the question had been gone into, and in 1864 the late Mr. T. Login, M. Inst. C.E., had sent in a scheme for a canal from Aknur, or close by. That had been rejected, on the ground that the estimates were based on such imperfect data as to be quite untrustworthy. The project had then been shelved, and nothing more had been heard of it until 1872, when Mr. Palmer had been sent there with a large staff to consider the whole question. The field-work had occupied 2 years, and eventually, in 1876, Mr. Palmer had submitted to the Government of India a project for one perennial canal to water the whole of the uplands, and two inundation canals, one from Ramnagar and the other from Chiniot, to water the low lands bordering the Chenab. That scheme had been rejected in 1877, on the ground that, in view of the problem-

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atical nature of the return, and the improbability of even getting a return at all, at least for a great many years, the Governor-General could not embark on a scheme of such magnitude. It had been shelved until 1882, when he had been superintendent of works of the Bari Doab Circle. Towards the end of June, 1882, in the middle of the hot weather, he had received a telegram directing him to send an officer to report on the Ramnagar inundation project. At the time his staff had been very short-handed; and having no officer available, and the matter being exceedingly urgent, he had sent a trusted native subordinate to pick up Mr. Palmer's levels. From his experience on that occasion he had learned the lesson that in a country such as India pegs would not stand for 10 or 12 years; exposed to the weather and white ants they quickly disappeared. Only with the greatest difficulty had a few of the points left by Mr. Palmer been picked up. Near Ramnagar, however, one of Mr. Palmer's lines had been found, and he had been able to go into the question. The proposal had been to take an inundation channel out of a branch of the river known as the Ramnagar Nullah, which, about 1872 or 1874, had been a fairly strong stream. But on his arrival there in 1882, things had changed entirely; the river had taken a set to its right bank, leaving the nullah without water, and rendering it useless to contemplate the construction of any canal to take off from it. Even in the heaviest flood probably not more than a trickle went down. On reporting that fact, he had been instructed to work up the river until he found a point suitable for a canal-head. He had carried out his instructions, at the same time pointing out that the place at which he had arrived, which was some miles above Ramnagar, was absolutely unsuited for the purpose of watering the low lands, and that an inundation canal was entirely out of place for the high lands. He had also asked that he might be allowed to put in a perennial canal, if the project was to be carried through. He had suggested that either Mr. Palmer's project of 1876 should be carried out, or a scheme should be commenced lower down the river, if that were found too high. After considerable discussion, his chief, Colonel Home, had written him a very kind and amusing letter, telling him to drink as much cold water as he liked, but not to pour it over this project; requesting him to do as he was told, and lay out the line; and prophesying that millions yet unborn would bless the day he went there. Of course, that had closed the subject, and he had had to lay out the line. The estimate had been prepared in Colonel Home's office, and had been

Colonel Ottley.

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Colonel Ottley. handed over to him to carry out. He had had a terrible time with the inundation canal, on which he had been engaged thenceforward until its opening in 1887. His contention all along had been that it would be impossible to take out from such a river as the Chenab an open channel which would not silt. Colonel Home had had a different opinion, and had thought that if the canal proper were begun about 4 miles down the line, and if a supply channel were made and connected with an escape to run back into the river, with a sharp slope of 1 in 4,000, or about 1·3 foot per mile, that would give a velocity of between 3¼ feet and 3½ feet per second, which would be quite sufficient to keep all the silt moving. He had had doubts about it; and, in the result, Colonel Home's hopes had been falsified, and it had never been possible to keep the canal free from silt. The worst months for silting were July and August. During those months 5,000 cubic yards of silt per day had been deposited in a channel of 109 feet bottom width; the total amount in a season having been something like 300,000 cubic yards, with a depth of 6 feet near the head. Nothing had availed to remedy that state of affairs, although he had tried dredgers, coolies and an alternative head. He had managed to get along in a way, but the canal had been a fearful anxiety and very unsatisfactory; as an instance he might mention that in September, 1886, a silt-clearance by coolies had resulted in the removal of 50,000 cubic yards. He had then re-opened the canal, and a few days later had obtained a discharge of about 750 cubic feet per second; but within a month the canal had silted up again, reducing the discharge to 202 cubic feet per second. Under such conditions it had been impossible to go on, and, therefore, while the canal was building, and in the early days of its working, he had kept hammering away at the question of a weir. The weir had eventually been granted, and in 1892 completed, and his anxieties in regard to silt had then come to an end. The weir had not been built at that site, one strong reason being that he had not seen how it would be possible to keep the canal open during the construction of the head-works. He had thought the best plan would be to go up to the Alexandra railway bridge, about 15 miles higher, which seemed to be an ideal site. But the railway officers had objected to his interfering with their works, and he had been unable to carry out the scheme without doing so. Apart from that, the piers caused such an obstruction of the bed of the river that, in the middle of the cold season, when all the pot-holes had been to a large extent silted up, he had sounded a depth of about 30 feet between the piers.

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Consequently he would have required a weir about 60 feet high; and, needless to say, the cost would have been so absurdly high that the scheme would have been put out of court altogether. He had therefore abandoned that spot, and had gone to one 2,000 feet lower down. There, on the same day as the 30-foot sounding had been obtained at the bridge, the deepest sounding obtained had been 6 feet. In accordance with instructions from Colonel Fred Home, who had succeeded his brother Robert Home, he had drawn up a complete estimate for a weir at that site, which would have had many advantages: for one thing, it would have commanded much more land than did the existing works. But, after careful consideration, Colonel Home —and he believed everybody else interested in the matter at that time—had thought it would be quite sufficient if a smaller area were commanded; and therefore, as at this site the project would be so much more costly than one lower down the river, he had been directed to choose another site. He had then gone 10 miles lower down the river, and had designed the weir afterwards carried out and completed in 1892. It might be thought rather an extraordinary thing that no one had known what the canal would do. He himself, and Sir Thomas Higham independently, had arrived at the figure of 1,100,000 acres. The most sanguine person had been his old friend Colonel Jacob, whose estimate of the amount of land which it would be possible to water had been 1,435,000 acres. Those opinions had been based on the best information obtainable from the older canals. It would thus be seen that Colonel Jacob's estimate, which had been regarded as absurdly sanguine, was too small by 1 million acres, while that made by Sir Thomas Higham and himself was out by 1½ million acres. It might be asked why that was so; and he thought there were two reasons for it. In the first place, he thought the head-works had been more successful than even he had dared to contemplate; so that much less silt came into the canal, and a larger supply of water was obtained, than had been anticipated. But there was a much more important reason, namely, that the carefulness with which the channels had been laid out and constructed, and the minuteness of the distribution, had resulted in an enormous economy of water. He was not aware whether the fact was generally known that, of every 100 cubic feet of water which came into the heads of the older canals, 70 cubic feet were absolutely wasted, only 30 per cent. of the supply doing any good at all in the way of irrigating crops. Obviously, if even a comparatively small fraction of that 70 per cent. could

Colonel Ottley.

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Colonel Ottley. be saved, the irrigated area might be largely increased. He believed that was what had occurred. Up to the time of the construction of the Chenab Canal, engineers had been working on the basis of the older canals; now a new departure must be taken. One great lesson was to be learned from the undertaking, namely, that the question of the saving of water, not on the main canals perhaps, but on the distributaries, must be very carefully gone into; and he was inclined to think that in the future it would be found worth while to make all minor channels absolutely water-tight. In regard to the remainder of the Rechna Doab, probably the day would come when a canal would be started from Mr. Palmer's point somewhere near Aknur, and the whole of the district would be irrigated. In that manner the procedure in the Ganges canals, where the upper canal had been made first, and the lower years afterwards, would be reversed. In the present instance the lower canal had been built first; and he hoped that before many years had passed the upper canal would be built. With regard to cross drainage, it would be observed that till the main ridge was reached the canal quartered the ground. In framing the estimate it had been anticipated that there would be practically no drainage—in fact, it had been stated that there was no drainage worthy of the name; and the total provision in the estimate for drainage had been £400. But before the canal was rendered safe he had put in nine drainage-works in the upper part of the canal, which were calculated to pass about 1,600 cubic feet per second; so that a good deal of drainage had had to be done. The reason was that the rainfall was capricious. When putting in a drainage at Ahmedpur he had determined not to be caught again, and had therefore put a bank across the depression, leaving a 50-foot gap, with gauges for registering what water passed that way. For 3 years the maximum discharge had been 147 cubic feet per second, and he had been actually considering the estimate of his resident engineer for a proposal to pass 400 cubic feet, when fortunately a rain-storm had occurred, during which about 8 inches had fallen in as many hours. Of course, both bank and gauges had been swept away; but it had been calculated that during the storm 3,870 cubic feet per second had passed down that depression, which for 3 whole years had never carried more than 147 cubic feet per second. Considerable difficulty had been experienced in dealing with this matter of drainage; all kinds of formulas had been tested, including one by Mr. Craig, and another by Colonel Dickens, but no satisfactory results had been obtained. It had been found

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Colonel Ottley.

by actual experiment that allowance had to be made for a discharge of between 28 cubic feet and 35 cubic feet per second per square mile of area, which was thought, as a general rule, to be fairly safe. He had already stated how difficult it had been found to pick up Mr. Palmer's survey: even when picked up it had not been of much use, because the lines had been spaced too far apart, namely, 5 miles. Practically no surveys had been made by Mr. Login in 1864, most of the work having been done without levels. In Mr. Palmer's time, 10 years later, cross sections had been taken 5 miles apart. In the Jhelum Canal survey, on the other side of the Chenab, he himself had spaced them 1 mile apart; Colonel Jacob had reduced it to about ½ mile apart; and now Mr. Preston had gone even further, to 1,000 feet apart. He was sure Mr. Preston was right in following that course, although he did not think it would be done anywhere but in such a tract as the Rechna Doab. The limit, he believed, had now been touched. If there was any truth in the old saying, "nothing succeeds like success," he thought the Chenab Canal had succeeded. Its success had doubtless fostered the revival of interest in irrigation in India, and he hoped other canals which took the Chenab for a model would be as successful.

Mr. Fitzmaurice.

Mr. MAURICE FITZMAURICE remarked that he was considerably interested in the two Papers, because during 4 years he had had every opportunity of seeing, in Egypt, not only the way in which large areas were administered in regard to the distribution of water, but also the different works required to enable the water to be brought on to the land. He agreed thoroughly with Mr. Buckley's comment on the gates of the Bhadar weir. Steel gates, which were largely used in Egypt, and which were easily managed, were much more effective than those described in the Paper. With reference to the cost of the work in the Appendix, he wished he could imitate in every undertaking the result that the estimated cost of the work had been £20,900, and the actual cost £20,734.

Turning to Mr. Preston's Paper, to an engineer, especially a young engineer who was keen about organization and administration, he thought there was no more interesting job than to be engaged on a large irrigation work. At the same time, the experience he had gained in Egypt showed that it was work entailing great responsibilities, decisions on important matters often having to be made at short notice. In addition, there were the difficulties arising from climate and dealings with natives. In dealing with natives, particularly where water was invaluable, the engineer must be careful that no partiality was shown towards any

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Mr. Fitzmaurice.

individual or village. Such a thing would not occur with any of the engineers; but they had to be careful that it did not happen with any of their subordinates who dealt with the distribution of the water. Several of the perennial irrigation canals in Egypt were much larger than the Chenab Canal, but in Egypt it was impossible to obtain the gradients which had been obtained in the Chenab. As the difference in the water-level of the Nile between Alexandria and Assuan, a distance of 750 miles, was only about 330 feet, it was difficult to get a gradient which would prevent the deposition of silt. In the Chenab Canal there was a gradient of about 1 in 6,000; in Egypt the gradient usually obtained was about 1 in 20,000. It was impossible to get anything like a velocity of 3 feet per second, consequently a large amount of silt was deposited, necessitating a considerable amount of dredging. He presumed that in the Chenab Canal there was a comparatively small amount of silt, which was also got rid of by dredging. He noticed in the Paper a statement that efforts were made to get the silt on to the land. He would like to know whether that land could grow crops with the help of silt and water alone, or whether it had to be helped by manure, or in any other way. Mr. Preston's Paper dealt almost entirely with administration: it was a pity that further information was not given in reference to the actual works needed for dealing with such an enormous tract of land; for he presumed there must be regulators and head-works to the canals and branches. Mr. McLean's Paper[1] did not say much on the subject, and it would have been interesting if more information on those points had been included in the Paper. The maximum duty expected from the canal appeared to be about 3,000,000 acres; already 2,000,000 acres were irrigated, or 66 per cent. of the possible maximum, which was a large and satisfactory percentage. But when, as the Author anticipated would shortly be the case, 2,500,000 acres were served, 80 per cent. of the total possible land would be irrigated. That result seemed to indicate excellent arrangements on the part of the engineers. He did not quite understand what the Author meant by saying (p. 162) that the total area irrigated amounted to 6,722,621 acres. It seemed to be the sum of all the acreage irrigated during about 10 years. A kind of danger-signal was hung out at the end of the Paper, where the rise of the subsoil-water was referred to. The rising of the subsoil-water, and the absence of proper drainage, were serious drawbacks in large irrigated tracts. In the Paper it was stated that it would not be possible to make any escape, because the escape would be so

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 314.

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close to the head of the canal; but it appeared to him it would be possible to make an escape some distance down, which would be effective in the event of the supply lower down having to be shut off on account of heavy rain or other causes. In any case it was necessary to have efficient drainage. Mr. Fitzmaurice

Mr. J. E. WHITING mentioned that he had had a good deal to do with the Bhadar project in the beginning, and his opinion had been asked as to whether it was a sound work. After going carefully into the matter with Mr. Benson, he had come to the conclusion that the works deserved all the care that could be given to them. On visiting the place he had seen first the weir at Gosa Bara for excluding the sea-water from the Mokul Rann. He had been pleased to see the extraordinary effect it had had in the short time which had elapsed since its construction. The land was improving, the floods were washing out the salt, and it was clear, from what was being done, that it was possible to improve the whole of the Mokul Rann, if water could be provided. He did not know whether the project was clearly understood; it certainly was not easy to understand it from the description given in the Paper. Mr. Whiting.

Having seen a good deal of irrigation work on the Indus, which was one of the rivers drawing from the Himalayas, he could not but feel the immense advantages which the engineers of the Chenab undertaking had had over those engaged on similar work in Sind. Their chief advantage, of which they had made use, lay in being able to cast a weir across the river. That was impossible in Sind; the river was far too large to allow of anything of the kind. All the canals in that part of India were inundation canals, though they had head-works. There were other advantages at the Chenab which had evidently been turned to very good account, judging from the Paper. It seemed to him a remarkable thing that after the canal had been worked for some time the coefficient N in Kutter's formula had been found from the discharge to be really 0·018 or 0·020, instead of the usual 0·025. Instead of making the canal worse as time went on, the deposit of silt seemed to have filled up the crevices and plastered the sides, and thereby to have improved the channels. He did not think that was usual in most parts of India; it was generally found that canals became worse as they grew older. Another remarkable thing was that the enlarged canal, designed to work with a depth of 9½ feet, was actually running 10·8 feet deep, and discharged 10,800 cubic feet per second, giving a velocity of 4 feet per second. The soil must be of splendid character to stand

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Mr. Whiting. such a current without being washed away. It was also stated in the Paper that the gradients were such that the velocity could be maintained throughout without any deposition of silt. One of the greatest difficulties experienced in Sind was the silt. The canals had to be cleared out periodically, and the silt, which consisted largely of sand and was of no use whatever on the fields, had to be deposited on the sides. If he understood the Paper correctly, in the Chenab Canal the engineers were able to carry all the silt, which was of a useful kind, on to the fields, where it was distributed: which was a great advantage. He thought there must be some deposits of sand near the heads of canals, and how they were dispersed had not been stated in the Paper, which did not refer to silt-clearances. In Sind, in parts of the canal far away from the head, where the water became clear, the whole canal was choked with weeds. The benefit of having such water as that in the Chenab Canal was that it apparently kept muddy during the whole of its course: because weeds could not grow in muddy water. If it could be arranged, where silting took place, that the silt deposited could be put into the canal at different times of the year, it would be a good thing. The Nira Canal was almost constantly filled with muddy water, or, at all events, water in which weeds did not grow. The canal head-works in that case were situated below a large stretch of land, on the banks of which, during the monsoon, an immense amount of alluvial soil was deposited. During the monsoon all canal water was muddy; and during the fine weather, when, in all other canals in the Deccan, the water became clear, the water in the Nira Canal did not do so; because on a long stretch of water, about 12 miles long and ½ mile wide, the banks were constantly being washed up, with the result that the water which went down the canal was muddy, and the growth of weeds was prevented. Another advantage enjoyed in connection with the Chenab Canal was that the engineers had been able to arrange where the villages should be placed, and where the people should live, so that fewer bridges were necessary. In fact, the engineers had everything under their own management and direction. The question of the distribution of the water was one of the most difficult problems the engineer had to study, especially in such an enormous tract, where water was so keenly sought after. Although the plan finally adopted in the Chenab Canal undertaking, of permitting water to be taken for a certain number of hours instead of restricting the quantity, was admirable, it must be inconvenient for one man to take his water for 4 hours at a stretch, obtaining all he

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could within that time, and then for the next man to take it for 4 hours, and so on. It would have been much better if the plan had been adopted of allowing every one to use the water simultaneously. It was not difficult to arrange outlets so as to discharge the share allotted to each man, whatever might be the depth of the water in the canal. Proportional outlets could easily be arranged by means of vertical walls in the canal built in brick. If, for instance, in a canal the ratios of the first, second and third outlets were 5 : 4 : 3, and the width of the canal at the first outlet was 12, then the outlet where the first man's distributary took off would be 5. The outlet would have vertical walls, and to whatever height the water rose, 7 parts would go on and 5 would go out into the distributary. Between that outlet and the next the width of the canal would be 7. The second outlet with vertical walls would take off 4 parts, and the other 3 would go on to the last outlet. Thus, instead of having only 4 hours in which to distribute the water, there would be 12 hours. It was much more convenient for a man with a large holding to have the water distributed slowly over it, and to have ample time for his work. The man could close his outlet altogether when he had had enough water, which would send more on to the next man, if he wished for it. It was possible that cultivators lower down might pay the man above for the water; but there was little harm in a cultivator selling his water to somebody else lower down who obtained the benefit of it, which was quite a different thing from bribing canal peons for the purpose of obtaining water taken from somebody else. So long as the cultivators gave the water to one another, he did not see any harm in it. Mr. Whiting.

Mr. C. W. ODLING observed that when irrigation had been commenced in Bengal 35 years ago, the great object of the authorities had appeared to be to prevent engineers from participating in the management of the canals. It had been considered that, as they were interested in the success of the canals, they might be rather harsh in their assessments, and might not treat the people with proper consideration. That policy had been bad for the engineers, because they had not been able to follow the water and see what became of it. Further, they had not been brought into intimate and constant communication with the cultivators, whereby they could ascertain what their grievances were. It had been worse still for the cultivators, who had been debarred from access to the persons who, if they had the authority, could prevent many of the grievances from arising. Eventually dissatisfaction had become so general that a Commission, of which he had been a member, had been appointed by the Government of Mr. Odling.

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Mr. Odling. Bengal, with a view to apply some remedy. After some time the Government had determined—not exactly in accordance with the recommendations of the Commission—to cast on the engineers the entire responsibility and management of the canals; not only the management, as in the Punjab, but also the collection of the revenue. The result had been entirely successful. Under the old system, the arrears had amounted to £10,000 or £20,000 a year, whereas in the last report he had been able to inspect they amounted to only £2. The objections to assessment had diminished in number, although the complaints had increased, because the cultivators immediately went to the engineers when they had anything to complain of. The revenue was not only punctually collected, but a much smaller amount was collected by coercion. When the cultivators would not pay, some kind of coercive process had to be applied, and before the engineers had undertaken the management it had been applied in a large number of the cases; now the number had been materially diminished. The change had been equally beneficial to the canal officer, who had to realize that only by growing good crops could the cultivator pay the water-rate. The crops depended on a timely and sufficient supply of water being available, which could be ensured only by incessant supervision on the part of the irrigation officer. Unfortunately, so far as Bengal was concerned, that supervision had to be exercised in the worst time of the year. The life of a canal officer had been described as devoid of all social and much domestic enjoyment. The reward he received was the contentment of the people he served; he did not get much recognition from his employers. It was stated that the Chenab Canal gave an amount in excess of the calculated discharge. The same had occurred in the Sone Canal, which gave 20 per cent. to 25 per cent. more than the anticipated quantity. For reasons already given by Mr. Buckley, all difficulty due to silt had disappeared. He had had an opportunity of inspecting the Chenab Canal in November, 1901, and what had struck him most was the fact that the villages looked as if they had been there for centuries. The only difference between them and the surrounding villages was that they had fairly good roads, and that some attempts at conservancy arrangements had been made. Industries of all kinds, including cotton-pressing and ginning, were springing up, and the Government had started a number of horse-breeding establishments. It was sincerely to be hoped that there would never be an accident to the canal. At present there were nearly 1,000,000 people on the land, and in a few years' time he believed there would be 3,000,000 · and as they were dependent on the canal for even

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their drinking-water, a disastrous calamity would happen if the canal water-supply failed. Mr. Olling.

Colonel JACOB remarked that Mr. Preston spoke of a fair duty for the water being 100 acres of crop per cubic foot per second during the rains, and 200 acres in the cold weather, or 300 acres in all per annum. The difficulty experienced by designers of canals in the past had been that they had never been permitted to allow for more than 200 acres: the authorities had not believed in the capabilities of the water. He was a little doubtful whether, in the old canals, even as much as the 30 per cent. mentioned by Colonel Ottley used to get into the fields—probably 25 or 26 per cent. was nearer the mark. Even now, if 300 acres per cubic foot per second was achieved, which was doubtful, only about 40 per cent. went on to the land, so that about 60 per cent. of the water was absorbed. The evaporation was so trifling in comparison that it might be left out of account; almost the whole of the loss was due to absorption. If it were worth while, the absorption, as Colonel Ottley had pointed out, could be stopped in a large measure. There was not the slightest doubt that the water must increase immensely in value, and for that reason it would be possible to go to far greater expense for the purpose of saving and conserving water than had been possible in the past. In that way vast possibilities were opened up for irrigation. Probably there were many present who did not understand how vital water was to India. It sounded pleasant to hear of a canal paying a dividend of 25 per cent.; but the lives of the people of India were infinitely more important than dividends. There had been a most appalling loss of life from famine during the past few years; he did not think anybody would put it at less than 10 millions, and he had recently seen an estimate which put it at 25 millions, although probably that was an exaggeration. With a growing population, the difficulty of providing the people with food became more and more acute, unless irrigation was possible. Railways were very useful in distributing food; but food could not be brought into India from another country, because the cost and difficulty of distributing it were so great. India must raise its own food, or the people would die; and they could raise their own food only by irrigation. Besides the preventable waste of water in the canals at certain seasons of the year, immense volumes ran to waste, even in the rivers which were most utilized. There were also large volumes of subsoil-water at no considerable depth. On the other hand, immense tracts of land were wholly dependent upon the rainfall, and Colonel Jacob.

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Colonel Jacob. were subject to periodical and appalling famines. Any one who had seen famine-stricken people, and the awful suffering entailed by starvation, knew what a serious matter was involved. Colonel Ottley had raised the question whether the existing Chenab Canal was the best canal that could have been made. It was easy to make a project for a scheme here or there which would pay a good return; but that was a different thing from making the best project, and so arranging it that it would not interfere with further projects, in order that the vast stores of water in one district might be applied in the best possible way to the immense dry areas in another. The matter under discussion would tax the utmost energies of the most skilful engineers, and would have to be worked out on far more scientific lines than had been the case in the past. Already tremendous strides had been made. Those who could look back 30 years knew the extraordinary developments which had taken place in the science of irrigation during that period; but the possibilities of the future were far greater. The work undertaken in the Rechna Doab was nothing to what would have to be performed in the future. Water would have to be conveyed far greater distances and over mighty drainages; and possibly it might be necessary to use machinery to lift the water, in a way which had never been contemplated in the past. Water was the life's blood of India, and it must be obtained at all costs; but great difficulties would have to be met and overcome. Mr. Preston's Paper described how some of those difficulties had been surmounted, what a great advance had been made, and how a far better duty was obtained than formerly. That was something to be thankful for, and it might be a stepping-stone to greater achievements in the future. The only way to look at the problem scientifically was to take a map and mark out the vast areas which must be watered, if the people were to be made famine-proof. Railways could distribute food to a certain extent, and were very useful in this way: but they could not produce grain, and their power was limited. People had starved in India a hundred miles from railways, because there was no way of carrying the grain over those 100 miles.

Colonel Pennycuick. Colonel J. PENNYCUICK remarked that Mr. Preston's quotation from Mr. Hawksley's Presidential Address, in regard to the want of knowledge existing in England of the work engineers were doing in India, might be extended; and it might be said that few engineers in India knew what was happening in more than one small part of the country. The two Papers under discussion would go far towards removing some of that ignorance. Personally,

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he would often have been exceedingly glad to know what had been done in other parts of India in connection with irrigation works; and he knew of more than one instance in which railway engineers could have saved themselves a great deal of trouble and expense, if they had been able or willing—he was not quite sure which, but he was afraid it was the latter—to take advantage of the experience of their colleagues in the Public Works Department. It might be asked why engineers in India did not communicate with each other more. One reason was that in India they were always extremely busy; another was the difficulty of communication, which was hardly realized at home. For all practical purposes, Madras, Bombay, and Calcutta were farther apart than Vienna, London and St. Petersburg, and often the first news engineers in Madras received of a work like that described in the Paper came from reading the "Proceedings" of the Institution. The work described in Mr. Benson's Paper differed in regard to physical and climatic conditions from that dealt with in Mr. Preston's Paper—a fact which illustrated the wide range of the work that engineers had to perform in India. About 4 years ago he had been present at the reading of a Paper[1] by Mr. Strange on large reservoirs in the west of India, and a year earlier he had the honour of contributing a Paper[2] on another work; so that, including the two Papers under discussion, he recalled four distinct works, which were quite different, and yet all came under the same general head of irrigation engineering. The work described in Mr. Benson's Paper was, so far as he knew, almost unique; the Author had apparently been helping Nature to create a delta. Nature had been trying to form the delta, but had not succeeded, because as fast as the delta had been formed it had passed away. The work carried out by Mr. Benson was an attempt to combine reclamation and irrigation. He was afraid it would be found in the future that the undertaking, like all work which tried to achieve two objects at the same time, would not be perfect for both. The site of the weir had been chosen very properly, with reference to reclamation; but he ventured to predict that in another 20 years, when the work of reclamation was completed, a new weir would have to be built about 8 or 10 miles higher up the river. The details of construction of the weir illustrated what he had already said as to the advantage engineers in India would gain by knowing what was being done in other parts of the country.

Colonel Pennycuick.

[1] Minutes of Proceedings Inst. C.E., vol. cxxxii. p. 130.

[2] *Ibid*, vol. cxxviii. p. 140.

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Colonel Pennycuick.

He thought the Author would have gained a great deal if he had known how engineers dealt with such works in Madras, where they were common. There they had found by experience that movable shutters on the top of a weir were abominations. They were sometimes necessary, but they were always evils. If used at all, they ought to be much larger than those used in the Bhadar weir. The numerous shutters, 4 feet square, which were liable to be floated up, and had to be held by ropes in order to prevent them from being washed away, were not desirable in such a situation. If he had had to deal with such a river in the south of India, he would have put in a permanent masonry weir for the whole 8 feet which was to be closed, and would have obtained an additional discharge by vents in the body of the weir, certainly not less than 8 feet or 10 feet wide, the shutters being lifted bodily. On two points he had some difficulty in following the Author's reasoning. It was stated that the height of 8 feet which was closed by movable shutters was opened in two halves, because if it were opened all at once, the scour would be excessive. He took it they were intended to be opened at some time or other, and probably when the flood in the river was at its height the whole 8 feet must be opened. Whatever scour was to be feared would be suffered then, and he could not see that it would be any greater if the whole 8 feet were opened at once, than if it were opened in two steps. Another reason given for limiting the discharge was that it would interfere too much with the river's banks, which were so soft that the river might change its position altogether; but apparently every other outlet had been closed, and it was very difficult for the river to change its course during the last 8 miles. Apart from that, it was stated by the Author that only a fraction—an insignificant part, he called it—of the whole discharge was sent through the weir. That was perfectly true, because in such a situation a flood-discharge of 180,000 to 200,000 cubic feet per second must be expected, and from the figures given he did not suppose the weir would discharge more than one quarter of that. Therefore the reduction by making the weir permanent up to 8 feet above the existing sill would certainly not raise the flood-discharge greatly, nor, if the drawings were correct, could it cause any serious difficulty. He hoped it would not be thought he was finding fault with the Paper; he only wished to emphasize the advantage of obtaining information as to what had been done in other works.

Mr. Preston's Paper was a singularly interesting one to him,

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Colonel Pennycuick.

because it dealt with a class of work of which he had had no practical experience, but from which engineers in Madras might learn a great deal. The most important parts of the works, from the constructive engineering point of view, were not dealt with in the Paper, the interest of which lay more in the administration and working of the scheme. One of the chief points which struck any one accustomed to work in the south of India was the extreme care with which the distribution had been carried out—a point which was apt to be neglected in Madras. It was only fair to say, however, that in Madras they had not such a clean slate as the engineers had had in the Chenab Canal, and were not able to lay out the village communities precisely to suit their convenience. Existing rights had to be dealt with; but, making every allowance for those, he thought the detail of distribution was far too much neglected in the south. He hoped his friends in Madras would study the work which had been done in the north, and follow it. One point which filled with envy an engineer who had been accustomed to work in the south was the high duty obtained from the water in the Chenab Canal. He thought the difference was not due entirely to the waste of water, as had been stated by Colonel Ottley, because he did not think that in the Madras canals there was anything like that waste; it was really due to climatic and other circumstances. More water was needed for raising crops. As far as he could make out from Mr. Preston's Paper, 1 cubic foot of water per second flowing continuously earned a revenue of something like 900 or 1,000 rupees per annum; in Madras half that revenue would be considered satisfactory, and naturally the figure quoted gave a much more favourable percentage return for the Chenab Canal. Both the works were exceedingly interesting. There was no question whatever of the magnitude of the work connected with the Chenab Canal, but he was not quite sure whether, from the point of view of engineering construction, Mr. Benson's Paper was not the more interesting of the two. Speaking as an old Public Works officer, he wished to express his thanks to Colonel Ottley for the extremely interesting information he had given as to the history of the Chenab project, which supplemented to a large extent that given by Mr. Preston.

Mr. Upcott.

Mr. F. R. Upcott remarked that one point had not been noticed, namely, the inclusion of a railway in the Chenab scheme of irrigation. That had been rendered easy on account of the embankment thrown up from the canal; and a good deal of the financial success of the project was due to the fact of the railway having been built. He had had a good deal to do with the railway

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Mr. Upcott. when it was first started. As the work had progressed, and as soon as the water had begun to flow and the crops to be cultivated, it had been found that there was an excess of food grain, and immediately a large export of grain had taken place. A few figures relating to irrigation over the whole of India might be of interest. He found from a blue book recently published by Parliament that, in the year 1901, the total area under irrigation in the whole of India had been 30 million acres; of which 13½ million acres had been irrigated by Government canals, leaving 16½ million acres irrigated from other sources. The Government main canals had comprised a length of 13,000 miles, with 31,000 miles of distributaries. Those figures would give some idea of the magnitude of the irrigation works in India. The financial success of the works all over India in 1901 had been such that, after paying 4 per cent. interest on the capital, there had been a surplus profit of 3¾ per cent. That was an extraordinary result, to which railways could not hope to attain for many years.

Mr. Robertson. Mr. F. E. ROBERTSON thought, from the diagram in Mr. Benson's Paper and the statement that on one occasion the mouth of the river had been choked, that there must be a considerable drift of sand to the northward along the coast. As it was stated that there was a lock provided in the weir, and sailing-boats were spoken of, it was to be hoped that the navigation of the river was not important; because it seemed to him that, when so much tidal area had been shut off, the mouth of the Bhadar must deteriorate, if not silt up entirely, except in times of flood. With reference to Mr. Upcott's remarks, as to the service the railway had probably done to the Chenab scheme, it was certainly true that irrigation by itself might keep the people alive in a district, but it was impossible to derive the full benefit from irrigation unless there were means of communication. He believed instances had been known in India of people being unable to pay their taxes because they had such good crops. It might not be immediately apparent why fine crops should be a curse; but it would readily be understood that if a cultivator had no means of selling his surplus crop it was of no use to him. He reaped as much as he could use; he could not sell any to his neighbours, because they all had the same crops; and the rest was left to rot in the fields, with the consequence that the cultivator could not pay his taxes. It therefore seemed that for an extensive plan of irrigation such as that described, some means of communication was a necessity.

Mr. Buckley. Mr. R. B. BUCKLEY wished, on Mr. Preston's behalf, to thank the members for the way in which his Paper had been received,

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and for the discussion which had taken place on it. It was undoubtedly the case, as Colonel Ottley had mentioned in his interesting and instructive remarks, that the great loss of water occurred in the distributaries; and if the distributaries and minor channels could be made water-tight, an enormous amount of water would be saved. But he was not able to agree with Colonel Ottley's statement that the losses were as high as 70 per cent. They might be in some cases, but they were not so in general. In that opinion he was confirmed by Colonel Pennycuick's remarks. In Bengal, also, a smaller percentage of loss was obtained. The silt in the canal was generally of an advantageous nature, and did good rather than harm. There was a certain amount of sand, but not much. Mr. Fitzmaurice seemed to think the silt was removed by dredging: that was not so. The velocity was kept at such a pitch that there was no appreciable deposit in the canal. While he agreed with what Colonel Jacob had said as to the excellent return yielded by the canals, he did not altogether agree with that speaker's remarks. No doubt the profit was an important matter; but it was of comparatively small importance compared with the great amount of good done. Colonel Jacob seemed to think that by irrigation alone famines could be prevented. Engineers would never be able to do that. The food which the existing irrigation works of India in the five principal provinces would save in a famine would be sufficient to feed about one-fifth of the population. If more works were constructed, more people might be fed; but sufficient works could never be built to feed the whole of the population. Although a large quantity of grain might be raised in one part, there must be a railway to carry that grain to the place where it was required. The advances made in the past half-century in the irrigation works of India had been very great. In 1856 or 1857 there had been about 3 million acres irrigated by Government works. A quarter of a century later, when Lord Mayo had introduced his system of constructing irrigation works from borrowed capital, about 10 million acres had been under irrigation, and at the present time the area was nearly 20 million acres, a somewhat larger figure than that given by Mr. Upcott. That advance had been of the greatest service to the country. An irrigation engineer had no greater pleasure than to see the good which the works did. It had been his duty 5 or 6 years ago, when a district with which he had been connected was afflicted with famine, to travel over many miles of main canals, and scores of miles of distributaries; and he had there seen luxuriant

Mr. Buckley.

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Mr. Buckley. and plentiful crops irrigated by the canal, while a few feet away from the tract which the water had reached the crops were scanty, and were being cut before they were ripe, to be given to the cattle. It was no exaggeration to say that, in that year, up to the line where the water went there had been plenty and prosperity, beyond it dearth and ruin. A result of that kind acted in a double way; because the people who, in such a year, got good crops by irrigation, sold their produce at enormously enhanced rates, and, while they fed their neighbours, made large profits for themselves. He could give more than one instance where the value of the crops saved by an irrigation canal in a year of famine had been equal to one-half or three-quarters of the entire capital cost of constructing the canal. Many references had been made to the size of the scheme described in Mr. Preston's Paper: he would make one more. It commanded about 3 million acres, while the entire cultivable area of Egypt was about 6 million acres. The Chenab Canal had therefore converted from a desert into a garden an area which was about equal to half of the cultivable land of Egypt.

Colonel Jacob. Colonel JACOB explained that he had no wish to decry railways; the engineer could not possibly do without them. He had meant that there must be irrigation to produce the grain in years of drought, as well as railways to carry the grain when produced.

Mr. Benson. Mr. BENSON, in reply, remarked that the simplest form of shutter had been adopted because (1) the weir was not to be worked under skilled supervision; (2) initial cost was low; (3) steel was avoided, as it corroded remarkably on the Kathiawar coast and would require painting twice a year, as had been proved on the railway. After the removal of shutters and guides the beams were raised and laid on the stone brackets shown in the cross section (Figs. 4, Plate 3). With regard to Colonel Pennycuick's remarks, 11 miles up the river was the territory of another chief, who might not consent to the building of a weir. The present weir could be raised, and would have to be lengthened when the flood spill area was much reduced. The alluvial soil between the Bhadar and Ojat rivers was so low and soft that no bank protection would render it safe to close the main channel with a solid weir.

Mr. Preston. Mr. PRESTON observed, in reply, that he was much gratified that so much interest has been evinced in the subject of his Paper, and regretted that absence on duty in India had prevented him from being present to answer the criticisms in person. He had never agreed with Colonel Ottley that it was a pity the larger scheme for the irrigation of the Rechna Doab, proposed by Mr.

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Login in 1864, had not been carried out; he thought it was a great mistake to have too many eggs in one basket, and, in his opinion, there was already quite as much irrigation on the Chenab Canal as it was safe to make dependent on a single weir across a river which might discharge in flood as much as 700,000 cubic feet per second. A scheme was now being worked out for a second canal which would take out of the river at or near Aknur, as proposed by Mr. Login, to irrigate the upper portion of the tract not commanded by the present canal; and he considered that the two canals built separately would be more efficient and more easily administered than a single canal. Mr. Fitzmaurice was mistaken in thinking that the amount of silt in the canal was comparatively small. It was so in the six cold-weather months, but directly the snows began to melt in the Himalayas, and floods caused by the monsoon rain came down the river, it was very considerable, the river often looking like pea-soup. An immense amount of warping had been done on the Chenab Canal to strengthen the banks in low ground, and the results showed that for 6 months in the year the quantity of silt averaged about $\frac{1}{2000}$ of the volume of the water. He had made a calculation from the statistics maintained of the supply which had entered the canal since its opening in March, 1892, and he estimated that 329,202,428 cubic feet of silt must have passed into the canal in the 10 years ending 31st March, 1902. Yet during that time, as far as he was aware, no silt-clearance had ever been made from the main or branch canals by dredging or otherwise. Some clearance had been made in the distributaries, both major and minor; but the great bulk of the silt had been carried right through the system and deposited on the fields, which it fertilized. With regard to Mr. Whiting's remarks, he thought there were two reasons for the difference between the Chenab and the Sind canals in the matter of silt-deposits: one was that the Sind canals were aligned in the low ground adjacent to the river, in which it was impossible to obtain the bed-slope necessary to generate a high velocity in the canal, which would carry the silt away; the other reason was that, being inundation canals, they had no weir for forcing the low supplies of clear river-water into the canals in the cold weather, which, with good velocities in the channels, removed any silt that might have been deposited. The experience in the Punjab inundation canals was the same as in Sind; the clearance of silt from them by manual labour every year was extremely heavy. Every branch canal, every distributary (whether major or minor), and every village watercourse was provided with a head regulator, and

Mr. Preston.

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Mr. Preston. furnished with iron gates and gearing for enabling the supply to be regulated in the channel. Mr. Fitzmaurice had misunderstood the duty anticipated from the canal, which was never likely to reach the 3,000,000 acres mentioned by him. The canal had been designed to irrigate 1,100,000 annually, and had already done 2,000,000; but it was unlikely it would ever exceed 2,500,000 acres. Mr. Whiting's suggestion that every cultivator should use the water simultaneously was impracticable; it was correct for the distribution of the water from the Government distributaries to the village watercourses, and was the practice actually in vogue; but the distribution of the water to the fields from the village watercourses, which was done in the manner described in the Paper, could not be done as Mr. Whiting suggested, as the volume of water would be too small. Such a channel might discharge 2 cubic feet per second, and be kept running for 10 days for the use of one hundred cultivators; it would be quite useless to give every cultivator 0·02 cubic foot for the whole 10 days; it would never reach the fields, and the whole volume would be lost in meandering about innumerable field-channels. Instead of this, the cultivator was given a larger volume for a shorter period, which rushed quickly on to his holding in a single channel; and when he had had his turn the same volume was given to the next irrigator.

Correspondence.

Mr. Arnott. Mr. M. H. ARNOTT thought a brief description of irrigation in Orissa might be of interest. The irrigation system there was altogether settled and scarcely any considerable addition was possible. There were three Divisions which comprised the irrigation portion of the Public Works Circle, and he would describe the working of the division of which he had been in charge, that of the other two divisions being similar. The canals from which the distributaries took off were as a rule used for both navigation and irrigation. One of them, however, the Machgang, in the division described, was used purely for irrigation, the locks at the head of each reach except the first never having been constructed. The head-sluice of the system was served from the Mahanadi River, which was entirely rain-fed, so that the supply was dependent on the rainfall over the catchment-area. As rice constituted fifteen-sixteenths of the crops irrigated by the canals, the scanty discharge available in the cold- and hot-weather months offered no practical

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difficulties, as when the demand for irrigation occurred in the rainy season there was always an ample supply available in the river. Irrigation commenced on the 15th June, and leaseholders were entitled to a supply until the 15th November. The only engineering work ever undertaken was the construction of village channels, known as "Minors." They were generally made on a petition presented by the inhabitants of one or more villages ("mouzas" in the vernacular), who complained that their area was not commanded by the canal or distributary, and said that if a minor were constructed they would all make a long lease. Sometimes they were so anxious for the construction of the channel that they offered, if Government would make it, to give the land on which it was to be built, free of cost; that was to say, Government would not be put to the expense of its acquisition. In all such cases it might be taken for granted that the undertaking would prove profitable to Government, as the villagers would be sure to bring their land under lease. Even where the land was not offered free, it would turn out profitable in nine cases out of ten, as the villagers would nearly always be sure to lease, although they might not see their way to relinquish the land free, generally on account of conflicting interests in the village or villages. After a petition was received, flying levels were taken, in order to see whether the area was commandable; if so, a longitudinal section and land plan were prepared by a subordinate and sent in to the Executive Engineer's office, for the preparation of the detailed estimate after the grading of the bed on the longitudinal section had been effected. The fall varied between 6 inches and 1 foot per mile, according to the level of the country; generally it was 6 inches per mile. In grading the bed the desideratum was to obtain a head of 6 inches over the highest fields, then irrigation all over the area was assured. This, however, was not always possible, as of course the bed might have to be lowered or raised, in order to equalize cutting and embankment. However, if 6 inches could be obtained it meant not only that the irrigation would be perfect, but that water would be conserved, as it would never be necessary to put that amount over the high fields for any length of time, if ever; as a rule 3 inches or 2 inches was sufficient. For the outlets the formula $v=5\sqrt{h}$ was used, and as regards the masonry works, they were all arranged in types varying according to the head over them: *e.g.*, with a small head there would be no wing-walls, and country-made pipes would be used; with a large head there would be wing-walls, shutters, and pottery-burnt pipes. The channel was

Mr. Arnott.

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Mr. Arnott.

designed by Bazin's formula, $v = C d \sqrt{\frac{R}{s}}$. The bed-width was supposed never to be less than 2 feet, height of bank above full-supply level 1 foot to 1½ foot, in and out slopes 1 to 1, and width of crest 1 foot, 2 feet, etc., according to the size of the channel. All local drainages were taken across by siphons, consisting of 12-inch pipes with concrete above and below when the catchment-area was small, and ordinary brick siphons when the area was larger. In submitting projects a note had always to be made as to the financial results that might be expected. Although the land in the irrigable area was flat as a whole, when the fields of an individual village came to be considered, it was found that some of them were high, others low, others did not require water except at times of drought, and some were suited in every way for irrigation. Also that certain areas, with fields such as those described, were separated by well-defined drainage-depressions, or by high ridges, and such areas were known among the engineers working the Orissa canals as "Blocks." One block thus differed from another in that it could be irrigated only by its own system of outlets, and by no outlets of another block. When the system now in vogue on the Orissa canals had been started in 1892, the plan had been to divide all the area commanded by the canals in each division into these blocks. Having done this, the next thing was to see that each village in a block was given a lease for such a number of years that it lapsed concurrently with the rest of the area. The object of this was obvious; for if all the areas in a block lapsed together and did not renew, the outlets serving the block could be closed at once, and misuse of canal water be prevented. If villages near the distributary applied for leases in a block they might be accepted, as the outlets could be reduced in size to meet the reduced area; when the areas farther away from the distributary or minor applied for leases, the diaphragm could be removed from the outlets. Thus leases were never taken indiscriminately, as to do so would vitiate the whole principle on which the blocks were worked. All the outlets were worked at a duty of 80 at the outlet, or of 65 at the head sluice of the distributary or minor; and the area was supposed to receive a continuous supply for 15 days. The assessment was carried out entirely by the engineering staff, and the collection by a special Deputy Collector who was in charge of what was known as the Revenue Division, his immediate superior, as in the case of the Executive Engineers, being the Superintending Engineer. One of the Deputy Collector's subordinates, known as

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the "Zilladar," was attached to each Revenue Sub-division, and it was his duty to assist in both assessment and collection. The method of assessment was the following. On an application for a lease being received by the Sub-Divisional Officer, he attached it to the authorized investigation form and sent it to the Sectional Officer for report as to the suitability of the area for a lease, etc.; after the latter's enquiry, he returned it to the Sub-Divisional Officer with the form filled up, and with a tracing of the map on the scale of 4 inches to the mile, showing on it the outlets from which the area would be irrigated, or, in the case of a new lease, their positions, the distributary, and the villages bounding the village referred to in the application. The form showed roughly the area of the fields that were to be assessed at a full rate, or at a reduced rate, or not at all, owing to their being so high as to be unirrigable, or so low as never to require water. This information was obtained by personal enquiry on the ground, with the help of the Settlement Survey maps 32 inches to the mile, and the Settlement "Khasrah," which, as stated in Mr. Preston's Paper, was a form having columns for the owner, occupancy, area, etc. Were these Khasrahs not in existence the work would be heavier than it was, as would be readily seen from what followed. On receiving the investigation form from the Sectional Officer, the Sub-Divisional Officer forwarded it to the Divisional Officer (who was the Executive Engineer) with the former's recommendation of the lease or otherwise; if recommended, he stated the number of years for which the lease should be sanctioned, the time depending on the considerations which regulated the block system noted above. After the Divisional Officer had returned the papers, duly sanctioning the lease, to the Sub-Divisional Officer, the latter forwarded them with the settlement Khasrah to the Zilladar for the preparation of the irrigation Khasrah. The numbers and areas of the fully irrigable fields were taken from the Settlement Khasrah by surveyors known as "Amins," and also those to be assessed at a reduced rate; the low-lying fields and high lands were excluded. When the Amin had finished his work, the Khasrah was returned by the Zilladar to the Sub-Divisional Officer for check, and after this had been done the Sub-Divisional Officer sent it back to the Zilladar approved, and with orders to prepare the Demand Statement or "Khationi," showing the number of fields belonging to each man and the total area to be assessed at a full or reduced rate, with the total amount payable by each lessee, and a column for his signature or thumb impression. It was at this point that delays took place, as the villagers often contended that some of

Mr. Arnott.

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Mr. Arnott. their fields had been wrongly assessed, some being too high and others fit only for irrigation at a reduced rate; and before they would sign, their objections had to be removed. In case the Zilladar failed to do this, he returned the Khasrah to the Sub-Divisional Officer with an "objection list," and the latter had to make personal enquiries again with the help of his Sectional Officers. The full rate for a term of years was 1 rupee 12 annas (2*s.* 4*d.*) per acre, and the reduced rate for land only requiring water in seasons of drought was 8 annas (8*d.*) per acre. Should the differences between the Sub-Divisional Officer and the villagers not be reconciled, and the irrigation of the area be an undoubted fact, it was assessed at a season-lease rate of 3 rupees 12 annas (5*s.* 0*d.*) against the men who had signed what was known as a "Provisional Lease," binding themselves to be jointly and severally responsible for the water-rate. The reason for using a provisional lease was that the Uriya cultivator would never apply for water when his lease lapsed until he was absolutely compelled to through the rain holding off and his rice being on the point of withering, and then there was not time to complete the lease. To enable him, therefore, to get water quickly, and so save his crop, water was supplied if the villagers, or a portion of them, signed for 75 per cent. of the area applied for. It was very seldom that the assessment had to be effected on the provisional lease, as if a few recalcitrant men would not sign the Khationi, pressure was brought to bear upon them by their co-villagers, who did not relish having to pay 3 rupees 12 annas per acre instead of 1 rupee 8 annas. After all differences had been reconciled and the Khationi signed, the Zilladar returned it to the Sub-Divisional Officer, who prepared the Permit which was sent to the Divisional Officer for signature with the Khationi and the 32-inch map, showing on it the classification of the fields in different colours. After signing the Permit and Khationi, the Divisional Officer transmitted them to the Deputy Collector, whereupon the latter realized the water-rates due. Season-leases for 1 year were practically unknown, as the rate was so much higher, and villagers invariably applied for a long-term lease extending over a period of 7 to 10 years; of course leases were granted for shorter periods, in order to make them lapse simultaneously on the principle already mentioned. The granting of long-term leases saved a vast amount of trouble, as, once the lease was completed, complaints were as a rule comparatively few; and if careful classification in the first instance was insisted on, they were reduced to a minimum. In the case, however, of a new lease coming in, and the classification taking place in the dry

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weather, when it was almost impossible to distinguish whether a field was irrigable, or high, or so low as to be assessed at a reduced rate, fields might be assessed at 1 rupee 12 annas: such mistakes were rectified during the next irrigation season. The system of long-term leases practically extinguished complaints of non-irrigation, for with the canal, distributaries and minors running full, a case of non-irrigation would show laxity of inspection on the part of the staff. The system of putting the assessment under the entire control of the engineers had been found to work very well. Before 1892 the engineers had simply turned on the tap, so to speak, the assessment having been done by a Revenue Superintendent under the Collector of the district; and the friction between the Engineers and Superintendent had been serious. Complaints of over-assessment from the villagers had also been numerous, as the land had been assessed yearly on the areas irrigated, which, as could easily be realized, would lead to harassment of the villagers by the subordinates employed. Also this led to the chance of areas irrigated being let off for a consideration, so that altogether the villagers had not known what their position was; and when nothing was settled in a system of irrigation it was fatal to its advancement and popularity. He entirely agreed with Mr. Preston's remarks that it was more advantageous to have the assessment under the control of the engineers. Mr. Arnott.

With reference to the granting of leases referred to on p. 158, it appeared that a great deal of labour was yearly employed in the assessment of the area irrigated; for if, for instance, a part of a field only was irrigated, it had to be measured, and this might occur twice in a year, if two crops were sown on the same field. There might be some reason for this laborious process, but otherwise, in starting a system of irrigation on Government land which was absolutely dependent on water for the production of crops, and which had formerly been a desert, it surely would have been possible to introduce an irrigation-tax on the whole irrigable area of each settler's holding, which he would have to pay whether he irrigated the whole of his holding or not in any year. The crop-producing power of the land on the whole irrigable area of the scheme must originally be the same, so that each settler would start fairly in that respect, and his improvement of the land would depend on his own individual effort and his skill as a cultivator. The introduction of such a tax would practically eliminate four out of the five of grounds of complaint enumerated on p. 158. The fifth was always liable to occur through wrong information being given

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Mr. Arnott. to the recording officer, frequently wilfully, for purposes of avoiding assessment.

Mr. Joyner. Mr. R. B. JOYNER remarked that the works described in Mr. Benson's interesting Paper were of a peculiar nature, and appeared to be more for the purposes of reclamation than for irrigation; but the circumstances were complicated, and it was not easy to follow the exact objects aimed at throughout, owing partly to the smallness of the plan and the lack of levels. The Author appeared to have devoted much care, thought and attention, to the design and work. It was evident that a weir for reclaiming land from the sea could not irrigate the land it reclaimed, nor in fact any other, unless the water was lifted. The principles aimed at seemed to be, to keep the salt water from overflowing and soaking into the lower lands, substituting fresh silt-laden water, and so warping up the low lands and keeping a more uniform level of fresh water within easy reach of the cultivable land-surface. He would like to know if this was so? Taking 60 square miles of land as practically gained from the sea, the total cost of all the works came to only 7*s.* 4*d.* per acre, which was remarkably low. In addition, there was fresh water available for lift-irrigation all the year, except in the monsoon when presumably it was not much wanted. It was possible that the depression of the Rann, or the raising of the shore, had been caused by the notable earthquake in 1819, which was said to have been responsible for the larger portion of the great Rann of Cutch. The Author stated that the water-way of the weir provided for only an insignificant part of the flood-discharge; and some explanation was needed as to where the flood went. It was not easy to make out from the illustrations the precise action of the weir-shutters. Presumably they were and could be fixed up only when the river was practically empty, the minimum discharge being perhaps run through the lock-gates; but if this was so there would appear to be occasionally some risk of not catching the right time for fixing them. If the guides were fixed in the hot weather, could the shutters be fixed when the river-floods had started? It would seem likely that the shutters would leak considerably, and, if so, it would be interesting to know the extent of the leakage. A form of weir-shutter which was cheap, easily opened and shut by ordinary labour, and effective in point of water-tightness, was a desideratum. It was possible that the Author would find it necessary to run a curtain-wall across the river-bed in the lower parts on the down-stream side, parallel to the weir, in order to protect it from scour. Judging from these works and from the collecting-tanks constructed or proposed, it was evident that the Native

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States concerned were keenly alive to the value of irrigation and land-improvement, and so set a good example to the Chief Government, which frequently found difficulty in providing funds for works, even when they would be of great and undoubted benefit. A general statement of the total expenditure and the total results of such works as that described in Mr. Benson's Paper should always be kept up and be available for reference. The most carefully-prepared designs and the most thoughtfully executed works were of no real value to the engineer unless they showed good financial results. Mr. Joyner.

Mr. Preston's Paper was highly interesting and instructive at a time when the important subject of irrigation was again attracting attention, not only in India, but in South Africa, where some Indian engineers were being appointed to advise the Government as to suitable irrigation projects for those colonies. The Author was to be congratulated upon the lucid and able manner in which he had described this most satisfactory outcome of over 30 years' experience of Indian irrigation engineers. Irrigation was not at all the simple operation which those who had not experienced its numerous great difficulties would think, especially in hot dry climates with variable supplies of water, and that water heavily charged with silt. The Chenab Canal was an excellent example, showing what could be done by the engineer in actually adding to the British possessions nearly 5,000 square miles of fertile territory, capable of producing, independently of rainfall, crops sufficient to maintain several million people; or which, if grown with wheat, would supply three-fourths of the total imports of that grain into the United Kingdom. The project was also a striking example of the value of systematic administration by officers of scientific training. The Author need not have apologized in any way for showing the value of the engineer outside, perhaps, his own particular line. It had been said that the future of the world was the engineer's—meaning that the complicated problems of advanced civilization and the inventions on which the world's progress would now so much more depend, must be dealt with by those possessing scientific training, instead of being, as hitherto, left more or less in the hands of those whose youth had been almost entirely wasted in learning languages dead 2,000 years ago. The magnitude of the work could scarcely be properly appreciated from the Author's modest description. Some idea of it might be formed by imagining a large river, over 280 feet wide and nearly 11 feet deep—exactly reversing nature, running at over 2½ miles per hour backwards, as it were, from its mouth up all its branches and up all the little brooks and ditches till the water was

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Mr. Joyner. finally run over every square foot of an area as large as the entire counties of Kent, Surrey and Sussex and most of Hampshire, every drop of water under full control, and every acre marked and numbered like the pages of a book! Yet this was only one of the many large irrigation projects so successfully carried out by English engineers in India, and almost entirely unknown to the general public. Coming to details, it would have been interesting if the nature of the soil had been described. Presumably it was the light-coloured silty soil deposited by the river in the course of ages; but if so, it was probably very sandy in parts. In that case, how was the great absorption prevented and how were the canals and distributaries kept from being choked by drift sand? In Sind, lower down, sand often caused much trouble, and the results of experience in avoiding this would have been welcome. The average rainfall for the past 11 years was said to be 11·81 inches, but during that time the land had been gradually brought under cultivation. It was to be hoped that records existed of the area for previous years, as the effect of the irrigation of large tracts of desert on the rainfall should be watched, and such opportunities as the Chenab scheme did not often present themselves. It was most probable that the rainfall over the Rechna Doab would be more than doubled, as the cool, moist, south-west monsoon winds passing over the great Rajputana desert became heated, expanded, and were enabled to retain their moisture, but when they met lands cooled by irrigation the moisture would condense and fall. Should the rainfall be increased, the people would become less dependent upon irrigation, and the duty per cubic foot per second would increase; this would point to the advisability of Government protecting itself by a land-rent, as well as a water-tax. It is not clear that this was arranged. Nothing was said in the Paper about regulators, either at the intake at the weir, or at the heads of the branches and distributaries; yet the Author wrote as if every drop was under control and the banks were only 1 foot to 3 feet above full-supply level, which seems a perilously small margin, considering how cattle going to drink, traffic, windstorms and thunderstorms quickly wore banks down. There must be regulators, and some description of them would have added much to the value of the Paper. In rivers heavily charged with silt, the successful working of regulators was a matter of great difficulty, as directly they were partly or wholly closed, silt was at once deposited, owing to the lessening of the velocity. Under some head of water silt frequently became too consolidated to be carried off by merely opening the gates. The question of silt was one of the great difficulties in designing and

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working an irrigation system from rivers which played about alluvial plains. In the lower parts of the Indus, into which the Chenab ran, in strong currents in the flood season $\frac{1}{10}$ part by weight of the water—and often more—was found to be silt; half of this was pure sand, which, being heavy, required a strong current to carry it, and was, of course, useless for fertilizing. The great object was to have such a current as would carry the fertilizing silt and not the sand; but then the latter accumulated, most probably at the head regulator, and arrangements were required there for carrying it off successfully. Details as to how this was arranged for—if the silt contained sand—would be of value. Another difficulty, which was not mentioned in the Paper, was to maintain everywhere the velocity which at all seasons would carry this silt and yet not scour the bed and banks. He had found in Sind that slightly less than 3 feet per second would be right; but a large canal designed to meet the heavy demand for water in the "khariph" season running full, would at other times be only half full, and consequently there would be a much decreased velocity, leading to accumulation of silt. This was sometimes very serious, and was not only expensive to remove but hindered the flow of water, to the great detriment of the crops. The Author mentioned that silt has to be removed at different seasons of the year. If there was plenty of water all the year round, the difficulty could be overcome—as he had proposed in Sind for a project very similar to but still larger than the Chenab —by running the canals and distributaries full the whole year and designing drainage-channels in the lowest levels, gradually increasing in size as the canals decreased, down which the surplus water escaped when not wanted for irrigation. By this means constant velocity was maintained, and a full head for command of all lands was given; while a fairly even head was maintained for the measurement modules. To show the cost of silt-clearance, in one engineer's district in Sind about 72 million cubic feet of silt had to be cleared every year from the ancient tortuous inundation canals; which was equal to the labour of digging annually a canal 350 miles long, 15 feet wide at the top and 5 feet deep. The Author did not mention any difficulty about the stability of the river at the canal-head; perhaps it was secure. The sudden shifting of the river-channel was often a great difficulty in irrigation systems in soft alluvial plains. He had known the Indus suddenly shift its position 6 to 8 miles in a year, leaving, of course, its canal-heads behind; and what was more astonishing, he had steamed in a launch over 20 to 30 feet of water and 2 years later had ridden over

Mr. Joyner.

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Mr. Joyner. the very same spot with the tamarisk bushes as high as his head! It was curious to find that the discharges of the canals increased with use; unfortunately his experience had mainly been the reverse, namely, that newly-made canals discharged more than they ever did afterwards, on account of growth of weeds, washing of banks from storms, etc., as well as uneven wear due to differences of material and silt-deposits. It looked as if the Chenab canals had really scoured their sides and beds. The question of "Reh" (efflorescence of salt) was an important one, not directly alluded to in the Paper; but it was seen that the risk of this destructive efflorescence was appreciated, by the care taken to avoid excessive irrigation where subsoil springs were high. If the Chenab scheme was to be a guide for the construction of other projects, it would have been well to lay stress on the great loss which too often occurred from over-irrigation in low districts from "Reh." But the important question of over-irrigation led to the troublesome question—troublesome in India, at least—of rates and manner of irrigating and delivering water. The system now generally adopted was a crop-and-season rate per acre, as in the Chenab project; but for many reasons it was unsatisfactory, even with such careful marking out of plots as had been done in that case. It led to fraud and peculation by the petty officials in combination with the cultivators, and to much expense in measuring and checking. It was a complicated system, as different crops required such different quantities of water, and the water as a rule differed so much in value, according to the time of year. It would be much better and simpler in all ways to sell the water by measurement. Those who had been used to lifting water by the "mot," or the "Persian wheel," or by hand, were very keen in their knowledge of quantities of running water and its value, and others soon become so. Modules might be fixed under lock and key to deliver under all circumstances certain fixed amounts of water, according to agreement, for a certain season: which would lead to great economy of water and would obviate all risk of "reh," the great cost of measuring crop areas, the irritating peculation, and the difficulty of checking the same. It would no doubt be said that a module for delivering, under all conditions of varying head and silt, a certain fixed quantity of water, had never yet been designed; but it could not be an impossible task, and he alluded to it in the hope of drawing attention to an urgent want. Again, nothing was mentioned about manure. This might not directly be an engineering question, yet it vitally affected the financial position of many irrigation works. It might be that in the Chenab

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a sufficiency of silt was got on to the surface of the fields; or the settlers might be using virgin soil, and so did not suffer from the want of artificial fertilization. But Indian cultivators always insisted that irrigation necessitated the use of manure much more than did rainfall. The question of "fallows" was an engineering one, as allowance had to be made in estimating quantities of water for certain areas; this was not mentioned either, possibly for the same reasons. Notwithstanding the high percentage of return shown on the outlay of the splendid work described in Mr. Preston's Paper, it should be noted that the Government had obtained fertile land under command of perennial water at a cost of under 13*s.* per acre; and the return included apparently no rent for the land nor any sums for its occupancy. The work reflected the highest credit on all concerned in its conception and completion, and they deserved the fullest praise from the engineering profession. Mr. Joyner.

Mr. G. H. LIST remarked that Mr. Preston's excellent Paper should go a long way towards correcting the prevailing ignorance of the work of the Indian Irrigation Department, and to disclose the magnitude of the work done, the importance of its effect on the body politic of India, and last, but not least, the quiet, untiring, self-sacrificing work of the Engineers of this famous Department. Some time ago an interesting series of articles had appeared in the London Press on Irrigation in Egypt and its progress to date. He had been sorry to see no mention in them of the Indian Engineers who had brought Egyptian Irrigation to its present high position. To the Indian Irrigation Department belonged the entire credit; and that department might well be proud of the members of their body who had repeated in Egypt what had been done in India. With regard to the railway mentioned in the Paper, it was now clearly seen that a railway should go hand in hand with a new canal such as the Chenab, in what was practically a desert. The line mentioned should have been made 3 years before it actually was constructed, and in the Jech Doab Canal scheme, now in hand, this mistake had not been repeated. Not only was the railway useful in getting labour, material, and supplies through, during construction of the canal; it was badly needed the moment irrigation began to bring in settlers and take away the produce raised. The line referred to in the Paper had been sanctioned only after repeated application and much opposition. It had had to be made as cheaply as possible, and not to cost more than Rs.30,000 (£2,000) per mile. The formation had been constructed by the canal engineers, because they had had full control of labour and material, and it had been judged Mr. List.

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Mr. List. inexpedient to have two agencies at work. Girders and permanent way were of second-hand material, from renewals on the main line. The only bridges were those over canals and distributaries; all other water-ways were "Irish bridges" or "dips" heavily laid with rip-rap. The length constructed was only about 90 miles, as the first 8 miles had been built some years earlier for taking material to the great Khanki weir. The line had been completed and opened for traffic in 12 months' time, and it had very soon been found that a serious mistake had been made in using second-hand permanent way. The line had simply been unable to carry the traffic offered to it, and it had been impossible to use powerful engines, or higher speeds than 15 miles per hour. Renewals in steel had had to be put in hand at once, much more siding-accommodation to be given, and extra stations to be opened for crossing trains. The extension to Multan had been built more substantially and laid with steel rails; and this line, which, when first sanctioned, had been intended to be worked almost as a steam-tram line, at a speed of 12 miles per hour, was now carrying a heavier traffic than many expensively-built trunk lines costing three times as much. This mistake was not being repeated in the line now under construction alongside the Jhelum Canal. One of the most pleasant of his experiences in India had been his association with the Author and other irrigation officers, in connection with the construction of this line, the original branch to the Khanki weir, and the supply of rip-rap from the railway quarries; more especially with Mr. Preston in settling the alignment and sending in the preliminary estimates for the Jhelum Canal line. He had thus been able to see and understand the immensity of the labour involved in maturing such an irrigation scheme as the Paper described, getting "behind the veil," as it were, in a manner that few outside the Irrigation Department ever did. He could have wished his career only beginning, and to be a canal engineer. There were still some grand projects to be developed. He knew them well from a railway point of view, and how depressing the districts were to travel through in the hot weather. Between Lahore and Multan stretched a tract 100 miles by 50 miles, still waiting for water from a weir across the Sutlej, near Ferozepur; and the great Sind-Sagar Desert, between the Indus and the Jhelum, a tract nearly 200 miles by 80 miles, awaited water from the big weir projected across the Indus at Kalabagh, where it debouched from the hills. With control of the sea, and possession of these grand wheat-lands of the Punjab, there need be no fear of failure of food-

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supply in England in time of war. Truly, the Irrigation Department of India was an Imperial Department in more senses than one. Mr. List.

Mr. PLAYFORD REYNOLDS remarked that, having been ordered by Government, about the year 1895, while Superintending Engineer of the Northern Division, Bombay, to report on the project devised by Mr. Benson—which he had been able to do favourably—he was in a position to offer some remarks on that gentleman's interesting description of the works. On the occasion of his visit the Gosa Bara bund or dam had been completed, and tidal waters had then been excluded from the Mokul Rann, a "Rann" being a low-lying plain, often a marsh, liable to submersion by the tides. He had found it an easy matter to free soil from the salts that rendered it unfertile, provided it could be washed freely and copiously by flood-waters, and drained. In the latter eighties he had carried out a large drainage-project in the Kadi Division of the Dominions of His Highness the Gaekwar of Baroda, when Chief Engineer of that State. The situation had been the following:—Many square miles of country had been totally unprovided with drainage, either artificial or by rivers or watercourses, with the consequence that during each monsoon the rain-water had collected in "bols" or depressions, some of them miles long, which had seldom overflowed, and then only into each other over flat saddles; the result had been that the natural salts which were abundant in the soil of the uplands had been carried in solution into the bols, where they had remained on and in the beds when the water had evaporated or had been absorbed into the ground. After generations, the soil in and around the bols had become barren, and increasingly so in area and degree with the lapse of time; and the cultivated area had decreased annually, to the loss of the cultivator as well as of His Highness's Government. By connecting the bols with drains, at the heads of which were waste-weirs and regulating-sluices, the monsoon flood-waters, when more or less saturated with salt, were run off and the salt thus removed. The crests of the waste-weirs and the sills of the sluices were designed so as to allow of retaining in the reservoirs, after the first floods, water sufficient to supply the domestic and other wants of the neighbouring villages. The purification of the soil by this process had been so rapid that, during the first cold weather, or annual dry season, succeeding the completion of the works, immense areas of splendid wheat and other grain crops had been grown on land where, within the memory of man, nothing had grown before. Mr. Reynolds.

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Mr. Reynolds. The areas so treated were far from the sea, so that the land had only gradually been contaminated and rendered barren; the case was different in the Mokul Rann, where the purification would be much slower owing to the frequent periodical submersion of the land by sea-water. Mr. Benson's project provided for the flooding of the whole 60 square miles of the Rann by the silt-laden floods of a drainage-area of 4,000 square miles, the effect of which by 1902 had been a rise of 2 feet in the level of a large area. An immense quantity of salt must, owing to its affinity for water, have been washed into the sea at the same time, over the Gosa Bara bund and through the main drain. It was to be noted that, by this project, water was stored only between the banks of the River Bhadar, as well as in the Sanbu and Ojat channels; the banks of the first were 600 feet apart at the weir, and 300 feet apart 7 miles higher up—for which length the river-bed was practically level—while the creek extended 5½ miles farther, so that the reservoir would not, as was usual, in what the Author, in common with many engineers in Bombay, called "tanks," spread over a wide extent of land, and irrigation would therefore be, to a large extent, if not altogether, by lift. This was a very favourable feature of the scheme, conducing to economy in the use of water for crops; because owing to the labour of lifting, the cultivator would not raise more water than was necessary. It was evident that on the right bank, at least, of the Bhadar, its character was deltaic; that was, the bank was highest near the river and descended towards the Rann: irrigation would therefore be by natural flow from the lifts westward. The water would probably be raised by Persian wheels, which were not uncommon on this coast eastward of Patan in the Gaekwar's territory, or by the "Mot," of which appliance *Fig. 2* was a sketch in section. Every part of the Mot could be made or repaired in every village, and it was applicable to a river-bank or to a well; the leather bag in its best form had a trunk, T, open at the upper end. The water raised was automatically discharged through the trunk on to a concrete platform, and flowed, through holes in the side walls of the platform, to the irrigation channels. Bullocks attached to the main rope supplied the power; they descended and ascended the slope shown in the sketch. With regard to the effect of the weir on the bed of the Bhadar River, it would be interesting to know whether it was being silted up. The Author stated that it was found difficult to keep the Sanbu channel open; so that he was already having experience of silting difficulties. In western Khandesh, where there were numerous weirs of varying heights up to 27 feet, the river-beds invariably silted up to the

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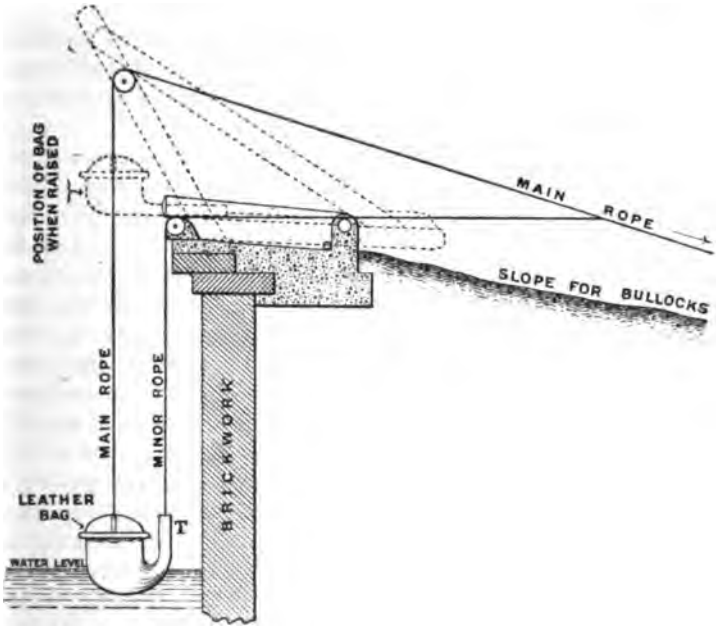
weir-crest: inasmuch, however, as these weirs were not for storage, but for raising the water-level in the rivers sufficiently for the water to flow down the canals, this silting was not a serious drawback. In the Bhadar, however, it would be otherwise. If and when its channel silted up, irrigation would no longer be possible to the same extent; in the meantime, however, the Rann soil would doubtless be fertilized throughout, much irrigation would be feasible from one or more of the "tanks," the sites of which were indicated in Fig. 1, Plate 3, and the rest of the Rann would, in

Mr. Reynolds.

Fig. 2.



years of good or fair rainfall, produce monsoon and cold weather crops, just as the rest of the surrounding country did. With regard to the streams other than the Bhadar, it was of interest to speculate what would become of them when the Mokul Rann was silted up; some would doubtless find their way or be trained to the Gosa Bara bund, others to the Bhadar. Another item of interesting speculation was the probable effect of irrigation and flooding on the subsoil water-level. At the site of the weir the river-bed was a tenacious clay with hard impervious limestone

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Mr. Reynolds. rock below, at no great depth. Similar conditions probably existed over the whole area of the Mokul Rann. The Author would no doubt be able to give the Institution his views on these points. The damage by floods to the stone filling mentioned, under the head of "working of the weir," as having occurred below the weir "to a depth of about 15 feet below the level of the sill," apparently extended to the lower side of the sill. The usual artifice was to make a water-cushion on the lower side of the weir; probably the Author had good reason for not adopting this precaution or remedy. As the estimated cost of the works—the actual cost was not given—was Rs.313,500, and, taking as the proportion of plant finally chargeable to works at half the original cost, *i.e.*, Rs.155,500, the total capital charge might be put at Rs.469,000. There were 42,000 acres irrigable, which, at the very moderate charge of 1 rupee per acre, would return 9 per cent. gross.

Mr. White. Mr. C. A. WHITE thought it would be instructive to learn in future years whether the obstruction to the tidal flow of the Bhadar River caused trouble from silting, and also to see how the iron, steel and teak withstood the corrosive action of salt water, and the attack of mollusca, etc. On the Bengal coast, cast iron was found to last better than steel or wrought iron, and teak was very soon destroyed by the attacks of different kinds of mollusca, unless sheathed with copper or other sheeting. Considering that, since 1898, a large portion of the 60 square miles of the Rann had been raised 2 feet by silt-deposits, it must be only a question of time for the whole of the Rann to be silted up, which would cut off the spill-area for the floods: would not this cause a serious raising of the flood-level at the weir; as 9,215 square feet of water-way could hardly dispose of a serious flood off a watershed of 4,000 square miles, liable in parts to a rainfall of 23 inches in 11 hours? Could Mr. Benson give an approximate estimate of the discharge of the highest recorded flood? Besides the proposed 50 lakhs of rupees for storage-reservoirs, would not a considerable sum be required for works for distributing the water over the Rann, and was there any probability of the revenue covering maintenance-charges and interest on the capital; or were the works only intended for protection from famine?

He desired to ask Mr. Preston for information on the following points:—The approximate proportion of the monsoon irrigation (rice) to the cold- and hot-weather irrigation (wheat, etc.); whether much silt was brought down by the waters of the melting snow; and whether there was any reason why the Bengal

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system of 5-year to 10-year leases of fixed blocks, 50 acres to 2,000 acres or more, should not be adopted, instead of the tedious method of noting and measuring annually the acres irrigated, field by field (about 1 acre each), which must require a very large subordinate staff. Mr. White.

Mr. G. B. WILLIAMS observed that Mr. Preston's Paper was so largely concerned with the administrative side of the Indian irrigation question, that he ventured to ask the Author to supplement it with some information about the Indian laws affecting the abstraction of water for this and other purposes. If the whole of the irrigation of India were in the hands of the Government, the legal question would be much simplified; but a large portion of the country was irrigated by private works; so that the question of riparian rights and prescriptive powers to abstract water must presumably be taken into consideration when constructing any work of the kind described in the Paper. On the importance of the legal aspect of the question Sir William Willcocks laid stress in his report on irrigation in South Africa, in 1901, wherein he recommended that, as a preliminary to any large scheme, the whole of the rivers and torrents throughout the Colony should be proclaimed as public domain. He cited the precedent of Italy, where a similar step had been taken on the consolidation of the country under Victor Emmanuel. The effect of imperfect legislation had been apparent in the United States, where the development of irrigation had been much hindered by the indefinite and contradictory laws in the various States. Riparian rights were not recognized throughout most of the Western States. In some places every owner of irrigable land appeared to have the right to obtain water from any convenient stream or river; while in other States, until recently, there appeared to have been no enactments at all on the subject. The origin of most of the European irrigation laws could be traced to Roman law, which regarded running water as being in the same category as air, a necessity of human life, which all might use but none could possess. A distinction was made, however, between the water itself and the rivers in which it ran, which were public property if navigable or capable of being made so, and usually private property in other cases. The right of conducting water through lands of another was recognized, and could be obtained by prescription, agreement or expropriation. French law considered rivers as public domain, and unnavigable watercourses were put into a class of things which belonged to no one. In Italy the rivers and streams were public domain, but springs were the Mr. Williams.

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Mr. Williams. property of the owner on whose land they rose. Under the old Spanish law, running waters were in some cases held by municipalities as a common property for domestic use, irrigation and other purposes. Many other examples might be given of the diversity of the laws in different countries which limited the use of water for irrigation purposes. He hoped Mr. Preston would be able to give some information as to the principles which had governed legislation in the country which contained the most successful modern examples of irrigation engineering.

Mr. Benson. Mr. BENSON, replying to Mr. Joyner's remarks, gave the following levels: lock-sill, 77·00; low tide, 78·00; weir-sill, 80·00; mean Rann level, 85·50; high tide, 86·50; full-supply level, 88·00 (which could be raised to the lock-coping and beam level, 91·00 when the Rann had been warped up); cultivated land near weir, 88·00; ditto 8 miles up river, 96·00; highest flood, 96·50. Land formerly cultivated was irrigated by lift. Much of the Rann was now under command. Eight villages had no fresh water in the subsoil, and depended on the Bhadar for their supply. The principles aimed at were correctly stated by Mr. Joyner; also the cost (7*s.* 4*d.*) per acre reclaimed. Similar land 20 miles south of the weir fetched Rs.11 (14*s.* 8*d.*) per acre per annum. The mouths of the river were rocky and narrow, therefore the high floods spread over the Rann, and fell into the sea at Porbandar, Gosa Bara, and Navibandar. With regard to the time at which the shutters were moved, the river was observed 80 miles up-stream and telegraphic intimation was given of a flood rising; the flood reached the weir in 18 hours. The shutters were in the meantime removed. This was generally done early in June. The weir was left open during the rains till the 1st of October, and closed then if there was no flood. The shutters were put in at a neap tide. If the flow in the river was too small to fill up the bed as quickly as the tide rose, and some sea-water was admitted into the river, the water was run out during the next low tide, and in a day or two the river was sweet. The slight leakage in the shutters was stopped by caulking. At the time of the paving referred to in the Paper the shutters had been water-tight. Silting up of the river above the weir was not possible, as the river was not interfered with during the monsoon, the only time when it could be scoured. The effect of the works was to prevent the removal of the silt deposited on the Rann during the monsoon. It was not claimed that they caused the deposition of silt in the Rann. The rivers flowing into the Rann would cut channels as the Rann silted up. The lake-like bed north of Kesod (Fig. 2, Plate 3) had silted, and the river now joined the Hugli. Training these would

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be out of the question, as wave-action would be severe on any banks. The subsoil-water was salt, and the drains must be lengthened as cultivation extended. The cost of the works given in Table IV. was actual, including plant: Mr. Reynolds had not quoted the figures given in the Paper. The mouth of the river would possibly be choked annually; but the trade had almost left this port since the construction of the railway to Porbandar 18 miles to the north. It would be beneficial if the mouth were closed annually before the monsoon, because the first floods, silt-laden, would be impounded (as in 1900) to a good depth over the Rann, and would deposit all the silt before bursting the sand barrier on the coast. The highest recorded flood (31 July, 1900) had risen from 89·50 to 95·00 (5·5 feet) at the weir in 10 hours—8 A.M. to 6 P.M.—when the sand barrier had burst. It had continued to rise for 12 hours, up to the level 96·50. The area within the 92·25 contour-line was at least 80 square miles. Therefore the river-discharge had amounted to 350,000 cubic feet per second for the 10 hours. This included the discharge at Porbandar (the only outlet) of 10,000 cubic feet per second. The mouth of the Bhadar viewed during this flood from Navibandar Fort, which rose from the rocky shore line, was a remarkable sight. The shelving limestone was nearly level for 2 miles along the shore, its crest being midway between low-tide and high-flood levels. Over it the water fell 18½ feet in an unbroken line, from a comparatively smooth lake on one side into the rough sea on the other. Mr. Benson.

Mr. PRESTON, in reply, remarked that no doubt leases, as suggested by Mr. Arnott, would be possible, but they had never been popular with the cultivators in the Punjab; moreover, irrigation was intimately connected with the land-revenue assessment of the country, and the policy of the revenue-officers of recent years had been to replace fixed win-or-lose assessments by fluctuating assessments on the crops actually matured, which, in his opinion, was a wise policy, as a fixed assessment must be low, in order to allow for bad years or indifferent yield. In reply to Mr. Joyner, the soil of the Rechna Doab was the ordinary light alluvial soil of the Punjab, but there were no sand-hills as in Sind or in the Sind-Sagar tract in the Punjab, and consequently the distributaries did not get choked with drift sand. Very careful records had been kept from the commencement of the construction of the canal, both of the rainfall and of the depth of the subsoil spring-level, and the gradual rise of the latter was watched carefully. In addition to the water-rates there was a land tax which amounted to about 1 rupee 4 annas, say 1*s.* 8*d.*, per acre. In Mr. Preston.

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Mr. Preston. connection with the weir across the Chenab River, there was an extensive system of training-spurs and banks, and there was therefore no anxiety as to the stability of the river. There were some "Reh" tracts in the Rechna Doab, but they were not very extensive, and it had been found that the soil of many of them had been much improved by growing rice for 6 or 7 years consecutively, after which it had been found possible to grow cold-weather cereals. In regard to the sale of water by volume, there was little doubt that it would be an ideal system; but there were extreme difficulties in the way. Measurement of the volume used by each cultivator would be necessary, entailing an enormous number of modules, which must be so designed that they could not be tampered with; and so far he had heard of none at a moderate price. The information given above replied also to the enquiry by Mr. White; but it might be added that leases to blocks of 50 acres to 2,000 acres might be suitable where there was a Zemindari proprietary, but would be impossible on the Chenab Canal where the land had been given out almost entirely in peasant holdings of under 28 acres. The following was the information asked for by Mr. White in regard to the proportion of crops grown for the year 1901–1902:—

		Acres.	
Hot-weather crops	Sugar-cane	60,871	
	Rice	35,937	
	Cotton	169,394	
	Indigo	111,308	
	Millets	106,732	
	Miscellaneous	181,866	
			666,108
Cold-weather crops	Wheat	796,332	
	Barley	22,408	
	Rape seed	131,076	
	Gram	13,375	
	Miscellaneous	118,830	
			1,082,021
			1,748,129 Acres.

In reply to Mr. Williams, the waters of all Indian rivers were the property of the State, and a royalty was charged to any individual who was permitted to take a private canal out of a river. Mr. Williams was incorrect in saying that a large portion of India was irrigated by private works, unless in "works" were included the innumerable wells in the country; there were some private canals, but they were not of large extent, the vast bulk of the irrigation canals belonging to Government. A special Act called the Northern India Canal and Drainage Act

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had been passed in 1873 (VIII. of 1873) which was applicable to the Punjab, United Provinces, and North West Frontier Province, and, under Section 5 of that Act, when the Government desired to construct a canal it issued a notification saying that from a date to be fixed the water of the river specified would be used in a projected canal. Mr. Preston.

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17 March, 1903.

JOHN CLARKE HAWKSHAW, M.A., President, in the Chair.

The discussion on the Papers by Messrs. Benson and Preston on "The Irrigation Weir across the Bhadar River, Kathiawar," and "Recent Irrigation in the Punjab," respectively, occupied the evening.

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Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3368.*)

"The Construction of the Mountain Section of the Cairns Railway, Queensland."

By George Alexander Hobler, Assoc. M. Inst. C.E.

The Queensland Government Railway between Cairns and Mareeba has a total length of 46 miles 50 chains, and was constructed in three sections, the work being let by a separate contract for each section. Section No. 1 is 8 miles in length; section No. 2 is 15 miles 18 chains (Fig. 1, Plate 5); and section No. 3, ending at Mareeba, is 23 miles 20 chains. In this Paper the Author presents a description of the principal works comprised in Section No. 2, the mountain section, of the line, and the general methods adopted in its construction.

Description of the country.—For about 60 miles northwards and about 100 miles southwards from Trinity Harbour, upon the shores of which Cairns is situated, there rises the face of an immense table-land at a distance from the sea-coast varying, approximately, between 1 mile and 15 miles. The height of this table-land ranges between about 1,100 feet and 3,500 feet above sea-level. The country between the sea-coast and the face of the table-land being practically flat, and having a rich soil, well watered, and covered with dense jungle, a humid atmosphere, with no frosts, and an annual rainfall ranging between 90 inches and 200 inches, is an ideal country for sugar-cultivation; consequently a large and increasing industry is carried on. The eastern face of the table-land is covered with heavy jungle, which extends back for a considerable distance on the top of the table-land. The soil is immensely rich, and the jungle is 80 feet to 150 feet in height, and is full of almost unlimited quantities of valuable timbers suitable for furniture, house-building, etc., including immense quantities of red cedar. The marketable trees of the latter range between 7 feet and 27 feet in girth at the butt, and in some cases attain a height of about 200 feet. The dense mass of undergrowth consists chiefly of lawyer thorn vines, stinging-tree, wild banana, creepers, etc., which render surveying a difficult and often a painful operation Severe frosts are occasionally experienced

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on the higher portions of the table-land, as much as 17° F. below freezing-point having been registered. Leaving the jungle country and going further west or inland, the country becomes very dry and barren, but immensely rich in gold, copper, silver, tin, lead, and other metals. Passing through the main tract of this mineral-bearing country further into the interior, large tracts of fine grazing country are met with, upon which a considerable number of cattle are raised.

It will, therefore, be seen that for the supply of provisions, etc., to this inland country, and in order to give facilities for opening up the mining, agricultural and pastoral industries, a railway up the face of this table-land, and running inland, was absolutely necessary. After a considerable amount of exploration and surveying, the Government decided to construct the line from Cairns, and it has now been completed as far as Mareeba, 46¾ miles, from which point the Chillagoe Company have continued it for a distance of 102 miles further west, with several branch-lines, and the Government have approved of the extension of a branch from Mareeba, 22 miles in length, along the table-land, parallel with the sea-coast, to tap the timber and agricultural land at Atherton.

Location of the Line.—The location of the line, especially the preliminary surveys, was an arduous and difficult undertaking, owing to the steep hill-sides, the dense jungle, and the hostility of the natives, who, at that time, were very treacherous, and constantly looted the survey-camps, besides spearing any white people who fell into their hands. Trial lines were run down from the top of the table-land, on gradients of 1 in 60 and 1 in 50, and from these cross-sections were taken and the permanent line was located. The ascent of the face of the table-land begins at 7¼ miles, near Redlynch Station on Section No. 1, at a height above sea-level of 18 feet (Fig. 2, Plate 5) and with the exception of 10 chains of level line at 11 miles, ascends by gradients ranging between 1 in 50 and 1 in 99, to 11½ miles; the ruling gradient on this portion of the section is 1 in 50, with 5-chain curves. Between 11½ miles and 14½ miles (Stoney Creek) a gradient of 1 in 60, with 5-chain curves, is maintained continuously throughout. Between 14½ miles and 19 miles 10 chains, the summit of the ascent, 1,073 feet above sea-level, the ruling gradient is 1 in 55, with 5-chain curves, the easiest gradient on this portion of the line being 1 in 103, for a length of 13 chains. Between 19 miles 10 chains and the end of the section, at 23 miles 30 chains, the line is practically level. The ascent from foot to top of the table-land is therefore 1,055 feet in 11 miles 70 chains, or an average rise of 88 feet per

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mile. With the exception of a 4-chain curve at Stoney Creek Bridge, and two other curves of 4½ chains radius, the sharpest curves are of 5 chains radius. In the total length of this section, 15¼ miles, there are 9 chains length of 4-chain curve, 14 chains of 4½-chain curves, 4 miles 20 chains of 5-chain curves, 74 chains of 6-chain curves, and 74 chains of curves not less than 7 chains radius, leaving 8 miles 67 chains of straight road. The minimum length of straight line between reverse-curves of 5 chains radius is 90 links. The average annual rainfall in this portion of the Cairns District is about 90 inches to 100 inches, and as much as 72 inches was registered in one month during the construction of this section. The principal portion of the rain falls generally during the months of January, February, March and April.

Carriage of Material and Plant.—Owing to the rugged nature of the country, the construction of dray-roads was not practicable along the site of the works. Pack-tracks were therefore made, contouring round the ravines and mountain-spurs, at formation-level of the railway. Tracks were also cut down the leading spurs of the mountain to the main Government camp at Kamerunga, and to the contractor's camp at Stoney Creek. Up and along these tracks, the plant, tools and explosives for culverts, earthworks, etc., and the cement and sand for concrete culverts, were transported on mule-back, mules being found more serviceable than horses. The sand had to be taken from the Barron River, none being obtainable in the gullies on the sides of the hill. The Portland cement was imported from England in barrels, each containing 4½ cubic feet. As the barrels were too unwieldly and heavy to lift and pack on the mules, thick canvas bags, each holding about 1 cwt. of cement, were made, and when filled were carried on the mules up to the site of the works. The sand required for use in the bridge-piers and culverts was also taken up in a similar manner. As the plate-laying advanced, the material was taken to the head of the road and was carried on along the line by mules. Sand and cement for lining tunnels were, of course, taken up by trains, the rails being laid through the tunnels as soon as these were excavated.

Clearing.—Owing to the steepness of the mountain-side, the distance to which the slopes of the cuttings ran back, and the great height of the jungle, a considerable quantity of clearing had to be done above these slopes, on the high side of the line. The clearing cost approximately £770 per mile.

Earthworks.—The earthworks were heavy, especially in cuttings and embankments. A large amount of benching in the seats of

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embankments had also to be done, owing to the steep slope of the hill-sides. The width of formation in cuttings and embankments was 14 feet, the formation being level across on straight road, and canted on curves to suit the super-elevation of the outer rail. No definite slopes could be fixed for the upper or higher side of the cuttings between about 12 miles and 19 miles, as, owing to the steep and treacherous nature of the ground, the slopes had to be suited to each individual cutting; they are, therefore, somewhat irregular, ranging principally between ½ to 1 and 1 to 1. The slopes of embankments are 1½ to 1. Cross-sections of the original surface of the ground were taken, and when the cuttings were completed cross-sections of the actual excavation were taken, at the same points of chainage, and from these the contents were calculated. The cross-sections were taken with the theodolite, readings on the staff being taken upon angles of elevation or depression. Owing to the curves in cuttings being, of course, principally concave towards the mountain-spurs, and the centres of gravity of the cross-sections considerably inwards from the centre-line of the railway, it follows that the product of the mean area of the cross-section and the length measured on the centre-line of the railway, would give in such curves much more than the actual volume of the excavation. Similarly, less than the actual volume would be given on convex curves. The following method of calculating the amount of excavation from cuttings on curves was therefore adopted. Each cross-section, after being plotted, was divided into sections by vertical lines 20 feet apart, measured from the centre-line. These were lettered A, B, C, etc. Tables were prepared giving the distances apart, measured parallel to the centre-line, of the middle ordinates of corresponding lettered sections. The mean areas of the corresponding lettered sections were then multiplied by the tabular distance apart of these sections. Many of the upper or higher sides of the cuttings exceed 300 feet in height measured along the slope, which, in such cases, is roughly ¾ to 1. By following this method of measurement in the cuttings between 12¾ miles and 18 miles, the total quantity excavated was found to be 2,261,482 cubic yards, whereas the volume obtained by multiplying the mean area of the cross-sections by their distance apart, measured on the centre-line, was 2,333,326 cubic yards, an excess of 71,844 cubic yards above that obtained by the more correct method.

Between 8 miles and 12 miles, and between 19 miles and the end of the section, the material excavated in cuttings was principally red soil and decomposed rock. Between 12 miles and 19 miles the

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country was of an exceedingly treacherous nature, especially in the Barron Gorge, between 16 miles and 19 miles, where the average angle of slope of the ground was about 45°. Almost the whole of the surface of the ground in this gorge was covered with a layer of loose disjointed rotten rock and soil to a depth of 15 feet to 25 feet. The line had therefore to be kept well into the hill-side, and the batters of the upper sides of the cuttings had to be carried up a great distance in consequence, Figs. 3, Plate 5. The cross-section at 16 miles 78 chains shows a large land-slip above the top of the cutting, which took place a few months after the cutting was finished to the original slopes. The earth appears to have slipped off a large greasy rock, and, since the opening of the line for traffic, has broken further back still, causing continual inconvenience during the wet weather, to which this district is subject. Between 16 miles and 19 miles there are only a few small embankments; the bulk of the material from cuttings on this portion of the section was therefore run right over the side of the formation in one handling. The total quantity of earthwork, including excavation for tunnels, culverts and bridges, was about 3,076,000 cubic yards. Of this amount, 2,823,983 cubic yards was in cutting to bank and spoil, 34,962 cubic yards was in side-cutting, and 74,169 cubic yards was in diverts, inlets and outlets. The actual cost to the contractor, of excavation in centre-cutting to bank and spoil, was approximately 2 shillings per cubic yard.

Bridges and Culverts.—The following riveted steel lattice-girder bridges were erected:—A bridge of one 100-foot span with timber approaches, the girders resting upon wrought-iron cylinders, 3 feet 6 inches in diameter, set in concrete; a bridge of one 100-foot span on concrete piers with timber approaches; a bridge of one 100-foot span on concrete abutments; a bridge of one 75-foot span on concrete piers with timber approaches; and a bridge of two 50-foot spans and one 30-foot span built upon a 5-chain curve, and having concrete piers at each end and timber approaches, the 30-foot span forming a tower-span between the two 50-foot spans, with wrought-iron lattice-piers, footed in concrete. A bridge at Stoney Creek Falls, built upon a 4-chain curve, consists of four 50-foot spans alternating with three 30-foot tower-spans, with wrought-iron lattice legs, the end piers being of concrete and the approaches of timber, Figs. 4, Plate 5.

The total length of steel bridges on this section is 800 feet. The contractor was paid £15 per ton for the erection of the sub-structure of all bridges and the girders of Stoney Creek Bridge, and £20 per ton for the erection of the super-structure of

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the other bridges. Altogether, there are 339 tons of ironwork in these bridges. The ironwork was all cut out and fitted and partly riveted up at Messrs. Walkers, Limited, of Maryborough, Queensland. The girders were sent from these works in sections convenient for handling in the steamers and on the railway, and when landed at the bridge-site, the riveting was completed, and the girders were launched into their places by means of derricks.

The total cost of the ironwork, delivered at Cairns, was £7,850; the cost of carriage to the site, and erection by the contractor, amounted to £6,330, making a total of £14,180, equal to an average price of about £42 per ton for the ironwork erected in place. The contract prices for the different portions of the ironwork, delivered in Cairns from Messrs. Walkers, were the following:—

Cast iron	£18 to £20 per ton.
Wrought iron	24 „ 28 „
Steel	23 „ 30 „

All the bridges were designed to carry locomotives with a maximum axle-load of 9 tons.

In addition to these bridges, fifty-nine wooden trestle-bridges were built, having an aggregate length of 6,215 feet, many of them upon 5-chain curves. On shallow bridges the spans are alternately 14 feet and 18 feet, without corbels, the two single girders being round logs 17 inches in diameter, faced on the top to receive the transoms and faced at the ends underneath to rest upon the headstocks. The deeper bridges have spans of 22 feet, 24 feet, 26 feet and 28 feet. The 22-foot spans consist of two double girders with corbels, and the 24-foot, 26-foot and 28-foot spans consist of three double girders with corbels, each double girder being composed of two logs 17 inches in diameter, faced where they rest on each other, and the upper one faced on the top for transoms. The trestles are built of two to five round piles, according to the height of the bridge and the span used; in deep bridges the outside piles are battered 1 in 6, and, if the line is curved, double piers 5 feet apart are used. The trestles are braced with sawn hardwood waling and bracing, 9 inches by 5 inches, and the transoms are of hardwood, 8 feet by 9 inches by 5 inches. The bottoms of the excavation for the trestle-piers were levelled up with cement-concrete, and on this the sills were laid.

In many of the ravines where the flow of water was not sufficient to necessitate the erection of a bridge, it was still found necessary, owing to the steepness of the ground, to build bridges, the ground being too steep for banks to stand, and adequate retaining-walls

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could only have been provided at a much greater cost than that of the bridges. For example, at 13½ miles a ravine having a drainage-area of 15 acres, and requiring a waterway of about 8 square feet, had to be crossed by a timber trestle-bridge, 252 feet in length, the sills of the trestle-piers being, in several cases, 60 feet below rail-level; the average slope of the mountain side at this place is about ¾ to 1. The minor waterways were provided for by concrete culverts, ranging between 2 feet and 7 feet in diameter, and also by log-culverts and box-culverts. The concrete used in culverts was gauged 4 of broken stone and 2 of sand to 1 of Portland cement. Concrete culverts were placed under deep embankments. Log-culverts were placed in shallow embankments where box-culverts could not be made large enough to carry the water. Log-culverts were made in the following sizes—2 feet by 2 feet, 3 feet by 2 feet, 3 feet by 3 feet, 4 feet by 2 feet, double 3 feet by 2 feet, and double 4 feet by 2 feet. They are constructed of side-logs, faced on three sides and tre-nailed together, the floor and top being made of split slabs and the headwall of dressed logs. Box-culverts were made of sawn hardwood, 2 inches in thickness, the maximum size of culvert used being 2 feet by 2 feet. In many of the ravines the upper sides of the banks were filled in to formation-level with spoil from the cuttings, and the water was divided and led by contour-drains to short culverts through the line at formation-level, at each end of the embankment, thus saving the necessity for long concrete culverts low down in the embankments.

During the construction of this section the difficulty of procuring good forest timber was very great, and a large quantity of jungle timbers was therefore used in the bridges, but with unsatisfactory results, these timbers proving unsuitable for piles, head-stocks, corbels and girders—especially for girders. At the same time, one of these timbers, hickory, has proved a very useful timber for backing-boards, foot-planking, sleepers, crossing-timbers, box-drains, fencing and house-building. From experience gained on this line in the maintenance of timber structures, the Author considers that in building railways through long stretches of tropical jungle, the employment of jungle timbers in permanent bridge structures should only be resorted to if it cannot possibly be avoided, and the most vigilant discrimination should be observed in the selection of the timber, for, apart from the risk of accident involved, the cost of maintenance and renewals constitutes a serious item.

Retaining-Walls.—On the flatter portions of the line, retaining-walls were made of dry-stone work, large roughly-dressed stones

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being used, well packed with spawls and with concrete copings on top. On the steep mountain-sides the walls were made of cement-concrete composed of broken stone, sand and cement, gauged 6, 3, and 1.

Tunnels.—There are fifteen tunnels on this section, Nos. 1 to 14 ranging between 56 yards and 196 yards in length, and No. 15 being 470 yards in length. The total length of tunnelling is 1,910 yards. Twelve of these tunnels are built partly on 5-chain curves. In Tunnel No. 11 there are 5-chain reverse-curves, and in No. 15 there is a 7½-chain curve at one end, a 15-chain curve at the other end, and a 5-chain curve in the middle. The cross-section of the tunnels is shown in Figs. 5, Plate 5. They are lined with cement-concrete throughout, the minimum thickness of the lining being 15 inches, increased to a maximum thickness of 21 inches in treacherous ground, where extra pressure was likely to occur. No inverts were put in, but footings under the side-walls were shaped to form water-tables on each side of the road. The tunnels are 17 feet in height from formation-level, 14 feet in width at formation-level, and 15 feet in width at 6 feet above formation-level, and are built for a single road. The formation was made level across, and the necessary super-elevation of the outer rail on curved portions was given by extra ballast under the sleepers.

The ground through which the tunnels were driven consisted almost entirely of disjointed rock of an exceedingly treacherous nature, and in such ground the contractor preferred to carry out the excavation by top-headings, except where the necessity of taking through material from adjacent cuttings, or for assisting the work beyond, made it more economical to use bottom-headings. In solid rock, top-headings were used. Top-headings were 9 feet by 9 feet and bottom-headings 11 feet by 10 feet. When widened out to full dimensions, the tunnel was timbered as shown in Figs. 5, Plate 5, and the permanent-way was laid to enable construction-trains to pass through. The tunnels, as excavated, were supported upon the timbers for 3 months to 15 months before the concrete lining was put in. This may be considered rather a long time, especially in country subject to a heavy rainfall, but practically no detrimental results were apparent from the practice followed. Particulars of the time occupied in excavating and lining each tunnel, including headwalls, etc., are given in the Appendix. In the majority of cases all timber was taken out as the concrete lining was put in. In a few instances it was considered impossible to take several of the crown-bars out without risking the collapse of the tunnel, and they were accordingly left

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in, being packed round with extra concrete. Tunnels Nos. 1 to 13 were lined throughout with cement-concrete composed of broken stone, fine sand, and Portland cement, gauged 4, 2, and 1. Nos. 14 and 15 were lined with concrete, made of river gravel and cement, gauged 6 to 1, the gravel being tested to ensure the presence of a sufficient percentage of fine sand. The tunnels are all on gradients ranging between 1 in 50 and 1 in 60. The concrete was mixed at the higher ends of the tunnels, except in Tunnel No. 15 which was concreted from both ends, so that the loaded trollies could be run down-hill to the point where the lining operations were in progress. The excavation was taken out as nearly as possible to the exact dimensions for concrete lining, cavities being packed with stone, and weep-holes provided at formation-level about every 10 feet. After the footings had been put in, the concrete lining was brought up on each side, with wooden centering; the side-walls were put in first, continuously, to a height of 11 feet 6 inches, then each side of the arch, leaving a keying-course of about 2 feet 6 inches in width, which was filled in from the end. In almost all cases, the tunnels being in very steep sidelong ground, the main thrust is at an angle of about 45°, and the Author is of opinion that, where the thrust of the ground is not vertical, the method adopted of building in the concrete lining is open to objection, it being essential that the lining should form a continuous bond. Subsequent events during the maintenance of the line have tended to support this view. In February, 1896, a shock of earthquake caused fracture of a portion of the lining at the Mareeba end of Tunnel No. 15. Apparently through the stone packing outside the lining of the outer or weaker side having been defective, the weight of the ground twisted the tunnel over a few inches, and the keying-course moved away from the inner half of the arch and slightly downwards; the thrust of the ground then fractured the inner half of the arch right down to the top of the side-wall. A length of about 60 feet of the lining, from the top of the side-wall on the left-hand side to within 2 feet of the footings on the right-hand side, had to be cut out and renewed. The lining was then built in sections of 6 feet in length and was carried round in one operation.

At Tunnel No. 15, the original survey ran round the outside of the hill, where it was proposed to build an iron bridge and two short tunnels, but having regard to the nature of the ground it was decided to put the whole of this part of the line into one tunnel. To prevent delay to the works which had been started along the line ahead of this place, it was necessary to drive the

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tunnel as quickly as possible, and for this purpose three adits were driven in from the side of the hill to the centre-line of the railway, and the driving of the tunnel was carried on from eigh faces at once.

The average quantity of excavation per lineal yard in tunnels was 32 cubic yards, the quantity of concrete required for lining being 8 cubic yards. The cost of the cement-concrete used in tunnels was about 55 shillings per cubic yard, including the cost of centering and general supervision. The cost of cement landed on the site of the works was about 20 shillings per cask, machine-broken stone costing 5 shillings per cubic yard and sand 2 shillings per cubic yard. The cost of mixing the concrete and putting it in place was, on an average, about 8 shillings per cubic yard. The cost of excavation was, on an average, about 15 shillings per cubic yard, including timbering and explosives; and the cost of the tunnels completed was approximately £46 per lineal yard. The driving of the tunnels was all done by hand.

Permanent-way.—From the beginning of this section to 9 miles 6 chains the road was laid with steel rails, 26 feet in length, of Vignoles pattern, weighing 41¼ lbs. per yard with four-hole strap fish-plates, weighing 10 lbs. per pair, the rails being spiked to the sleepers with $\frac{9}{16}$-inch dog-spikes. The remainder of the road was laid with 60-lb. steel rails, 24 feet in length, of Vignoles pattern, with four-hole strap fish-plates, weighing 15 lbs. per pair, the rails being spiked to the sleepers with $\frac{5}{8}$-inch dog-spikes. The rails were bent with a hand screw-press. A portion of the sleepers were of sawn timbers, 6 feet 9 inches, by 9 inches, by 4½ inches, and the remainder were half-round, cut from trees ranging between 10 inches and 1 foot in diameter. The timber principally used for sleepers was hickory from the jungle, and bloodwood from the forest country. The contractor's price for sleepers was 3 shillings each. Gravel ballast was procured from the bed of the Barron River at Kamerunga, to which place a temporary branch-line, about 1¾ mile in length, was laid. The contractor's price for ballast was 4 shillings per cubic yard. There are 2,640 sleepers to the mile on straight road, and curves flatter than 7 chains radius, and 2,880 sleepers to the mile on curves of radius not exceeding 7 chains. Approximately 960 cubic yards of ballast was used per mile of line, the depth of ballast under the sleepers being 4 inches. The Author is of opinion, from experience gained in the subsequent maintenance of this line, that in tropical countries having a heavy rainfall and a humid atmosphere, where the growth of grass and weeds constitutes a serious item in the cost of maintenance, gravel

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ballast is much superior to broken-stone ballast, the cost of weeding being reduced to approximately one-sixth. The roots of grass and weeds in gravel can be easily, quickly, and effectively removed, whereas in broken stone the roots break off in the metal and sprout up again almost immediately; the broken metal also cuts and jars the men's hands.

The gauge of the line is 3 feet 6 inches on the straight, and the rule now in force with regard to the gauge on curves is that it shall be 3 feet 6½ inches on curves of radius not exceeding 7 chains, and 3 feet 6¼ inches on curves of radius between 8 chains and 20 chains. The weights and costs of the permanent-way material used are given in the Appendix. The maximum speed round sharp curves allowed on this section is 18 miles an hour for passenger-trains, and 15 miles an hour for mixed passenger- and goods-trains. The rates of wages paid by the contractor throughout were, for labourers, 8*s.* per day, gangers, 12*s.* per day, carpenters, 12*s.* to 14*s.* per day, hammer- and drill-men, 9*s.* per day, and for plate-layers 8*s.* and 9*s.* per day.

Locomotives.—The engines at present in use on this line are of two classes, known as "B 13" and "B 15" of the Queensland Railways. The former has six wheels coupled, the diameter of the wheels being 3 feet 3 inches, and the wheel-base 10 feet 4 inches; the cylinders are 13 inches in diameter, and the load on each axle of the coupled wheels is 5¾ tons. The weight of the engine is 23 tons 16 cwts., and of the tender 22 tons 10 cwts., or a total weight of 46 tons 6 cwts. The "B 15" class of engine has six wheels coupled, 3 feet in diameter, the wheel-base being 8 feet 9 inches; the cylinders are 15 inches in diameter, and the load on each axle of the coupled wheels is 7 tons. The weight of the engine is 27 tons 19 cwts., and of the tender 23 tons 15 cwts, or a combined weight of 51 tons 14 cwts. From Redlynch to Kuranda the "B 13" engine hauls a load of about 80 tons, and the "B 15" engine 120 tons, exclusive of engine and tender.

The survey of this section was commenced under Mr. Robert Ballard, M. Inst. C.E., then Chief Engineer of the Central and Northern Division of the Queensland Railways, and was continued under the late Mr. Willoughby Hannam, M. Inst. C.E., Chief Engineer of the Northern Division, under whom also the works were designed and the construction partly carried out. The work was finally completed under Mr. T. H. Annett, Mr. Hannam's successor. The construction was commenced in January 1887, and was completed in June 1891. The total amount paid to the contractor, Mr. John Robb, exclusive of arbitration fees, was

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£894,916, equal to £58,779 per mile. Rails and fastenings and iron-work for the iron and steel bridges were provided by the Government Railway Department, and the cost of these is therefore not included in this amount. All the surveys were carried out by the Government Railway Surveyors. The Author was engaged as Assistant Surveyor in the survey of the line and in the preparation of drawings, and afterwards as Assistant Engineer in the construction of the line, and on two occasions had charge of the work as Acting Resident Engineer, for about 5 months and 7 months respectively, during the absence on leave of Mr. J. G. Gwynneth, the Resident Engineer. On the completion of this section, the Author was appointed District Engineer for Maintenance and Construction in the Cairns District.

The Paper is accompanied by two tracings, from which Plate 5 has been prepared; and by nine photographs, and the following Appendix.

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APPENDIX.

TIME OCCUPIED IN EXCAVATING TUNNELS, INCLUDING HEADWALLS, ETC.

Tunnel Number.	Commenced.	Completed.	Work Done During First Month.	Work Done During Last Month.	Total Excavation.
			Cubic Yards.	Cubic Yards.	Cubic Yards.
1	June, 1887	September, 1887	360	440	2308
2	June, 1887	September, 1887	128	150	2723
3	July, 1887	April, 1888	188	48	3864
4	July, 1887	May, 1888	30	50	3271
5	August, 1887	July, 1888	50	485	2842
6	August, 1887	May, 1888	90	50	3920
7	August, 1887	February, 1888	20	40	1809
8	July, 1887	October, 1888	60	70	3714
9	September 1887	November, 1888	40	5	6338
10	April, 1888	June, 1889	25	5	4021
11	September, 1887	May, 1889	50	5	2968
12	January, 1888	August, 1888	10	264	2881
13	April, 1888	September, 1889	90	10	3126
14	March, 1890	June, 1890	..	10	2999
15	12 April, 1890	November, 1890	..	10	15264

TIME OCCUPIED IN LINING TUNNELS.

Tunnel Number.	Commenced.	Completed.	Total Concrete used.
			Cubic Yards.
1	31 August, 1888	17 October, 1888	594
2	September, 1888	November, 1888	698
3	25 October, 1888	23 January, 1889	978
4	20 January, 1889	20 April, 1889	834
5	28 January, 1889	22 April, 1889	726
6	3 April, 1889	31 May, 1889	994
7	20 April, 1889	27 May, 1889	474
8	25 May, 1889	20 July, 1889	938
9	31 May, 1889	20 August, 1889	1586
10	24 July, 1889	18 September, 1889	1018
11	17 August, 1889	30 September, 1889	758
12	28 September, 1889	9 November, 1889	738
13	22 October, 1889	9 December, 1889	794
14	19 July, 1890	4 October, 1890	766
15	3 November, 1890	30 March, 1891	3791

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WEIGHTS AND COSTS OF RAILS AND FASTENINGS PER MILE OF LINE.

41½-Lb. Material.—Rails, 64·82 tons; fish-plates, 1·82 ton; fish-bolts, 0·50 ton; dog-spikes, 2·36 tons.

60-Lb. Material.—Rails, 94·28 tons; fish-plates, 2·95 tons; fish-bolts, 0·93 ton; dog-spikes, 2·65 tons.

The approximate costs of rails and fastenings delivered at Cairns from England were—

41½-Lb. Material:—

	Per Ton. £.	s.	d.
Rails	5	8	0
Fish-plates	7	0	0
Fish-bolts	16	3	0
Dog-spikes	16	6	0

60-Lb. Material:—

	Per Ton. £.	s.	d.
Rails	6	11	0
Fish-plates	8	4	0
Fish-bolts	17	14	0
Dog-spikes	17	4	0

QUANTITIES OF THE PRINCIPAL ITEMS OF WORK, ETC., BY FINAL MEASUREMENTS.

Clearing	15¼ miles.	
Earthworks:—		
Cutting to bank and spoil	2,823,983	cubic yards.
Excavation in water-tables	828	„ „
„ „ drains at ends of cuttings	1,664	„ „
„ „ side-cutting	34,962	„ „
„ „ side-drains	22,253	„ „
„ „ diverts, inlets and outlets	74,169	„ „
„ „ benching seats of embankments	4,454	„ „
„ „ station-yards	624	„ „
Surface forming	51	lineal chains.
Fencing	585	„ „
Iron and steel bridges:—		
Excavation for foundations for piers	10,426	cubic yards.
Cement concrete in piers	3,138	„ „
Iron and steel work	339	tons.
Painting	7,081	square yards.

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Timber bridges:—	
Excavation for foundations, etc.	36,264 cubic yards.
Cement-concrete under wooden trestle-piers	1,538 „ „
Round timber in piles, headstocks, girders and corbels	74,398 lineal feet.
Sawn timber in transoms, wales and braces, footplanks, longitudinals and backing-logs	23,130 cubic feet.
Ironwork	135,758 lbs.
Painting	26,122 square yards.
Tarring	8,215 „ „
Timber and concrete culverts:—	
Box-drains 12 inches by 12 inches to 24 inches by 24 inches	2,852 lineal feet.
Log culverts 2 feet by 2 feet to 7 feet by 2 feet	913 „ „
Earthenware pipe-drains 3 inches to 18 inches in diameter	5,253 „ „
Excavation for concrete in culverts	2,888 cubic yards.
Cement-concrete in culverts	1,119 „ „
Retaining-walls:—	
Dry-stone work	419 „ „
Cement-concrete work	577 „ „
Tunnels:—	
Excavation in tunnels	62,048 „ „
„ „ side drives—tunnel No. 15	1,602 „ „
Cement-concrete in tunnels	15,687 „ „
Stone packing in side drives	288 „ „
Earth-filling in side drives	511 „ „
Stone pitching—9 inches deep	643 square yards.
Permanent way:—	
Sleepers	38,351
Ballast	14,645 cubic yards.
Squared timber in points and crossings	146 „ feet.

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(*Paper No. 3383.*)

"Mountain Railways."

By GEORGE DEUCHARS, M. Inst. C.E.

THE following is an attempt to reduce to figures a comparison between mountain railways of different gradients in a comparatively simple assumed case; and is intended to illustrate a method which might be applied to any given mountain-railway project, to assist the judgment of the engineer in deciding on the best line. It is thought that the figures referring to probable engine performances, including fuel-consumption, which have been assumed for the purposes of an estimate, approximately represent average results in every-day working; but further information on this subject would be valuable. The figures under working expenses are based on general averages, and, of course, would have to be modified to suit any particular district considered.

The load which an engine can move on any gradient is limited solely by its adhesion (or by the strength of the rack teeth, etc.), assuming of course that the cylinders are big enough, and the speed at which that load can be hauled up the gradient is a question of boiler-power, or the quantity of steam which the boiler is capable of producing per hour.

Let W_e denote weight of the engine in tons, including the tender, if there is one.

„ W_t „ . maximum gross weight of the train, in tons, which the engine can pull up the gradient G.

„ S „ speed in miles per hour.

„ G „ virtual gradient per cent., *i.e.*, the actual gradient plus a gradient equivalent to the train resistance, taken for the purposes of this Paper at 0·5 per cent.

„ F „ force in tons applied to the rails at the periphery of the driving-wheels.

„ HP „ horse-power developed, at the periphery of the driving wheels.

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Then $$F = (W_e + W_t) \frac{G}{100} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and $$HP. = \frac{2,240 \times 5,280}{60 \times 33,000} \times F S$$

$$= 6 F S \text{ (approx.)}$$

$$\therefore HP. = 0{\cdot}06 (W_e + W_t) G S \quad . \quad . \quad . \quad (2)$$

Equation (2) gives the horse-power required to propel an engine and train of given weight up a given gradient at a given speed.

Let C be the horse-power which the locomotive may be expected to develop, at its driving-wheels, per ton of its weight. Substituting in equation (2)—

$$C W_e = 0{\cdot}06 (W_e + W_t) G S \quad . \quad . \quad . \quad (3)$$

an equation which, if C is known, gives the weight of train which an engine may be expected to take up a given gradient at a given speed.

In order that an engine may pull a given load up a given gradient it must of course be able to exert the necessary force F on the rails, and in doing so there must be no slipping of the wheels. This slipping of the wheels is prevented, on an adhesion-railway, by the friction between the driving-wheels and the rails, and on a rack-railway by the strength of the rack teeth. If K be the "coefficient of traction," or the ratio of F to W^e at the point of slipping, then the first condition that must be fulfilled is given by the following equation :—

$$K W_e = (W_e + W_t) \frac{G}{100} \quad . \quad . \quad . \quad . \quad (4)$$

The two equations (3) and (4) give all the information required concerning the relative weights of engine and train in any given case.

Combining these two equations—

$$S = \frac{C}{6 K} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

from which it is seen that, no matter what the gradient is, if an engine is loaded with the maximum train-load which it can pull on the gradient, the speed at which it will pull this load depends simply on the coefficients C and K. Thus, if C = 6 and K = $\frac{1}{8}$, then the load which the engine can pull up a given gradient is given by equation (4), and, no matter what that gradient is, the engine

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will be capable of pulling this load up at the rate of 8 miles per hour.

Practical values of C and K.—Particulars of mountain railways all over the world are given in the Appendix, Table I.

In column 19 of that Table are given values of C, and these will be seen to vary between 5 and 9, the latter figure being exceptional and probably unreliable. The figures in the Table must be accepted with caution, as they are based on somewhat vague statements as to speed; and the loads given are in some cases not above suspicion. Moreover, the figures represent the results of special trials, and not of every-day working. The value of C is not constant for the same engine at different speeds, since it depends upon the piston-speed. This will be referred to under the heading "Locomotives." For present purposes the values given in Table II. are assumed:—

TABLE II.

Speed. Miles per Hour.	Value of C.		
	Tender-Engines.	Tank-Engines.	Rack-Engines.
4	3·7	4·3	4·8
5	4·0	4·5	5·3
6	4·3	4·8	5·7
7	4·6	5·2	6·1
8	4·9	5·5	..
9	5·1	5·7	..
10	5·3	6·0	..
11	5·5	6·2	..
12	5·8	6·5	..
13	6·0	..	..
14	6·3	..	..
15	6·5	..	..
20	7·3	..	..
25	7·7	..	..
30	8·0	..	..

The figures in this Table are not intended to represent the best attainable, but a working every-day average, which will doubtless be exceeded by some engines, while others will fall short of it. For example, engines having grates unusually large in proportion

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to the total weight of the engine (the grate-area, in square feet, is usually equal to one-fourth to one-third of the total weight of the engine and tender in tons) may probably give higher values of C at the expense of fuel. Engines having any device for increasing the piston-speed, such as abnormally small wheels, will give higher values of C. The value of C will also probably be comparatively higher for small engines, owing to greater ease in stoking. The value of C will also of course depend upon the quality of the fuel. The figures given assume a fairly good coal—equal, say, to Bengal coal. The figures in Table II., as giving the values of C between 4 miles and 15 miles per hour, agree sufficiently closely with the following empirical straight-line formulas:—

$$C = 0{\cdot}26\,S + 2{\cdot}8, \text{ for tender-engines.}$$
$$C = 0{\cdot}28\,S + 3{\cdot}1, \text{ „ tank- „}$$
$$C = 0{\cdot}42\,S + 3{\cdot}2, \text{ „ rack- „}$$

Combining these with equation (5)—

$$S = \frac{2{\cdot}8}{6\,K - 0{\cdot}26} \text{ for tender-engines} \quad . \quad . \quad (6)$$

$$S = \frac{3{\cdot}1}{6\,K - 0{\cdot}28} \text{ „ tank- „} \quad . \quad . \quad (7)$$

$$S = \frac{3{\cdot}2}{6\,K - 0{\cdot}42} \text{ „ rack- „} \quad . \quad . \quad (8)$$

Equations (6), (7) and (8) give directly the approximate speed which may be expected up any gradient if the engine is loaded with a full load corresponding with the value of the coefficient K. S can also easily be found from equation (5) and Table II. by trial and error.

In column 21 of Table I. (Appendix) are given values of K in the different cases. About $\frac{1}{4}$ appears to represent a safe value of K for a rack-and-adhesion railway. The values of K for adhesion-lines vary very much, and depend in the first instance on the kind of engine employed, and the proportion of the total weight of the engine upon the driving-wheels; and, second, on the coefficient of friction between the driving-wheels and the rails. This coefficient of friction of course varies within wide limits—between about $\frac{1}{4}$ and $\frac{1}{15}$, depending upon the climate of the locality. Thus climatic conditions have a great influence in determining the most suitable kind of railway for a particular locality. A line which could be worked profitably by adhesion in a dry region, when the coefficient of friction might be $\frac{1}{4}$, might not be so worked in a locality subject to frost and snow.

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For ordinary working conditions, where frost has not to be reckoned with, the following values of K for adhesion-railways may be taken :—

Class.	——	Values of K.
B	Fairlie, Shay geared, or other tank-engines with all the weight on the driving-wheels	$\frac{1}{4}$
C	Tank-engines with leading or trailing wheels . .	$\frac{1}{6}$ to $\frac{1}{10}$
D	Tender-engines	$\frac{1}{11}$ to $\frac{1}{15}$

Theoretical Traffic-Capacity.—The term "Theoretical Traffic-Capacity" is taken to mean the quantity of paying load which can be transported per hour over a given distance by the railway under consideration, supposing the railway to be worked to its fullest theoretical capacity.

Let T denote theoretical traffic capacity in both directions.
„ N „ number of sections into which the line is divided by crossing-stations.
„ L „ length of line in miles.
„ S „ speed in miles per hour.
„ t „ minimum stoppage time at each station.
„ m „ the ratio of the paying load to the gross train-load (excluding engine).

Then
$$T = m\,W_t \times \frac{1}{\left(\frac{L}{NS} + t\right)} \quad . \quad . \quad . \quad . \quad (9)$$

To prove this formula, let *Fig. 1* represent a graphic time-table of the line when it is being worked up to its full capacity.

Let OX represent times.
„ OY „ distances.
„ A, B, C, etc., be the positions of the crossing-stations.

The theoretical traffic-capacity is equal to the paying-load multiplied by the number of trains per hour. The number of trains per hour in both directions is obviously inversely proportional to the length Oa,

Thus
$$Oa = \left(\frac{\frac{L}{N}}{S} + t\right);$$

hence
$$T = m\,W \times \frac{1}{\left(\frac{L}{NS} + t\right)}.$$

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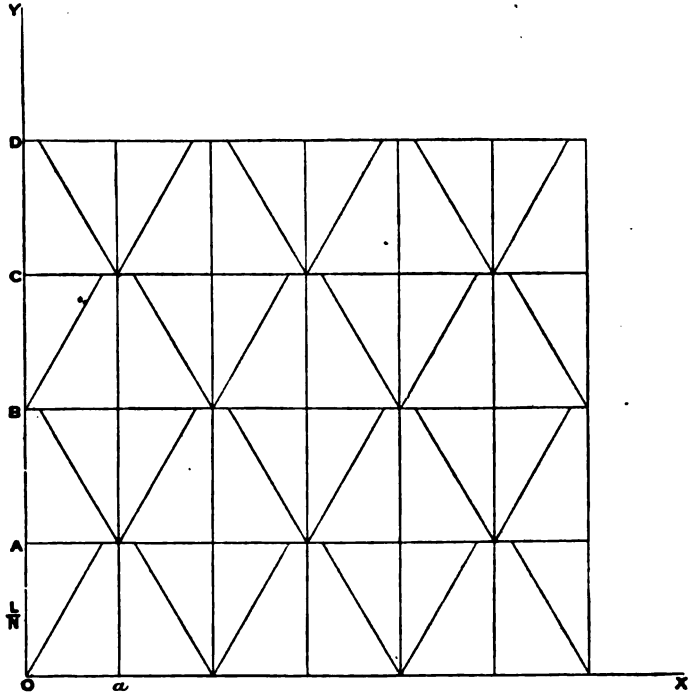
W, and S can be found for any given gradient and class of engine from equations (4) and (5).

The following example will illustrate the method to be employed in investigating any particular case. The difference in level between two places to be connected by a railway is 6,000 feet; what will be the relative theoretical traffic-capacities of railways on gradients of 1 in 8, 1 in 12½, 1 in 25, and 1 in 40, with either rack or adhesion? The intervening country is supposed to be of such a

Fig. 1.



nature that a continuous 1-in-8 gradient is obtainable in a more or less direct line; and it is also supposed to be capable of allowing other lines having gradients of 1 in 12½, 1 in 25, or 1 in 40 to be obtained by development. The line is to be of metre-gauge with a limiting axle-load of 10 tons.

Engines of the following dimensions will be assumed under the different classes:—

Class A.—A semi-tank-engine in the form of a 60-ton Fairlie engine supported on two six-wheel bogies and carrying coal-

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bunkers only, the water being carried in a separate tender, weighing 15 tons in working order.

Class B.—A 60-ton Fairlie engine carrying coal-bunkers and water-tanks.

Class C.—A 55-ton tank-engine with eight driving-wheels and leading and trailing pony-trucks.

Class D.—A 48-ton tender-engine with a 20-ton tender; total weight 68 tons. Engine with eight driving-wheels and a leading pony-truck.

Engines of this size on a metre-gauge line under Classes C and D would require specially wide fire-boxes, carried over the wheels.

From equations (4) and (5) are found the weight of the train which can be hauled in each case by an engine of this weight, and the speed. Thus with a tank-engine of Class C, with $K = \frac{1}{9 \cdot 6}$, equation (4) becomes—

$$\frac{1}{9 \cdot 6} W_e = (W_e + W_t) \frac{G}{100}$$

which gives the weight of train it is capable of hauling, and equation (5) becomes—

$$S = \frac{C}{6 \times \frac{1}{9 \cdot 6}} = 1 \cdot 60\ C.$$

From Table II., this equation is approximately satisfied for a tank-engine if S [1] = 9 miles per hour. Similarly for the others. The number of crossing-stations will be limited by the smallest time-interval at which it is practicable or convenient to handle trains. This time-interval may perhaps be assumed as, say, 0·30 hour for an Indian railway. Thus, if the running-speed be 12 miles per hour, the minimum distance apart of the crossing-stations will be $12 \times 0 \cdot 30 = 3 \cdot 6$ miles. The relative theoretical traffic-capacities for the different gradients are then compared by constructing the Table given in the Appendix Table III.

It will be noticed that in this comparison $\frac{L}{NS}$ and t in equation (9) are constant, and that consequently the "Theoretical Traffic Capacity" varies directly as the train-load hauled.

In estimating the value of m, the maximum capacity of a truck is

---

[1] S may also be found directly from equation (7):

$$S = \frac{8 \cdot 1}{6K - 0 \cdot 28} = \frac{3 \cdot 1}{0 \cdot 345} = 9.$$

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taken as twice its tare-weight. In practical working the ratio of paying freight to capacity hauled may be taken at 0·40 as a general average for loaded trucks and empties.

Let W_t denote gross weight of train.
„ L „ paying freight.
„ T „ tare weight of train.
„ W_t „ L + T.
and L „ $0{\cdot}4 \times 2\,T = 0{\cdot}8\,T$; or $T = 1{\cdot}28\,L$.
$\therefore L = 0{\cdot}44\,W_t$.

If therefore the gross train-load hauled were always the maximum possible, the paying-load might be taken as 0·44 max. W_t. In actual working it is impossible to work to this, owing to fluctuation of traffic and to the fact that only by accident would a number of trucks, with varying loads, amount, in the aggregate exactly to the maximum load, when made up into a train.

If an average gross train-load of 80 per cent. of the maximum be assumed, then,

$$L = 0{\cdot}44 \times \frac{8}{10} \text{ max. } W_t = 0{\cdot}35 \text{ max. } W_t = \frac{1}{3} \text{ max. } W_t \text{ (approx).}$$

In the case of the Darjeeling-Himalayan Railway the yearly goods-train mileage is 150,000 train-miles, and the net ton-mileage 38,000 × 41·71 = 1,580,000 ton-miles, giving an average of about 10½ tons of paying freight in a train, the maximum gross train-load being 35 tons. The theoretical traffic-capacities given in Table III. (Appendix) do not of course represent even approximately the actual traffic-capacity to be expected, as trains are assumed to follow one another with clockwork regularity and with no margin for delays, accidents, etc.

Practical Traffic-Capacity.—The "Practical Traffic-Capacity" may be taken as the number of tons per hour which can be delivered in daylight-working. This will be a better gauge of the capacity of the line in actual working, as it will allow a large margin of 12 hours per day for irregularities. Delays occurring during the day can be made up in the night. A very large margin is required, since the unpunctuality or failure of any one train will throw out the working of all the others. The theoretical traffic-capacities given in Table III. (Appendix) represent the number of tons of goods which could be delivered per hour, supposing each railway to be worked continuously night and day with clockwork regularity. If working be confined to daylight, and trains start out every morning from each terminal, the "practical traffic-capacity" of each line will be a variable fraction

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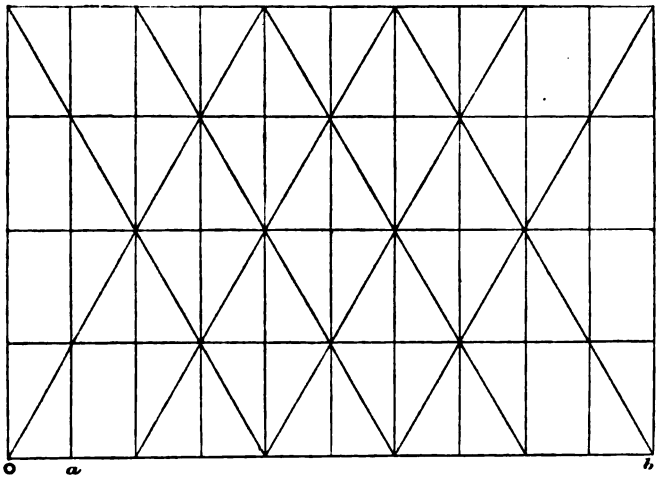
of the figure found as "theoretical traffic-capacity," and the relative traffic-capacities will work out quite differently.

The maximum numbers of trains which can be run in daylight-working with a working-day not exceeding 12 hours, and supposing trains to start each morning from the terminals, are shown in Table IV. (Appendix). This Table is arrived at by drawing graphic time-tables for different numbers of crossing-stations. Thus, for example, *Fig. 2* would represent a graphic time-table for three crossing-stations, where O*a* is the time taken in running between crossing-stations plus the stoppage at the station. The

Fig. 2.



following very liberal allowances have been made for stops at stations for watering and fuelling :—

For an engine which has been running continuously for about	1 hour or more	0·4 hour
" " " "	¾ "	0·3 "
" " " "	½ "	0·2 "

For example, for an engine of Class C on a 1-in-25 gradient,

$$\text{Time between stations} = \frac{28 \cdot 40}{4 \times 9}$$

$$= 0 \cdot 79 \text{ hour.}$$

$$\text{Stoppage} = 0 \cdot 3 \text{ "}$$

$$\therefore \text{O}a = 1 \cdot 09 \text{ "}$$

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A day's work would be represented by 10 times $Oa = 10{\cdot}9$ hours, or Ob, which, in *Fig. 2*, represents four trains each way. Similarly for all the others.

In Table IV. A. (Appendix) are shown the actual and relative practical traffic-capacities in a daylight-working of 12 hours, and it will be seen that the relative practical traffic-capacities work out quite differently from the "theoretical traffic-capacities" in Table III. (Appendix). The influence of the time occupied in the journey, as affecting the "Practical Traffic-Capacity," is seen by comparing the capacities as found from Tables III. and IV.A. (Appendix).

Adhesion-lines on gradients steeper than 1 in 20 or 1 in 25 may be put out of court, unless for exceptional cases, partly on account of their low traffic-capacity and partly from considerations of safety. Adhesion-gradients of 1 in 25 can be safely worked with vacuum-brakes or with screw-brakes on each vehicle. Rack-lines on gradients flatter than 1 in 25 may similarly be put out of court on account of their low speed, and consequent low traffic-capacity. It will be seen from Table IV. A. (Appendix) that even in the case of 1-in-8 gradient the traffic-capacity is $7{\cdot}30$ tons per hour, or $7{\cdot}30 \times 24 = 175$ tons per day. Considering that the average daily traffic handled by the Darjeeling-Himalayan Railway, which is fairly busy for a mountain-line, is only about 100 tons, and considering further that the capacities given in Table IV. A. (Appendix) can at once be approximately doubled by running double engine-loads, it would appear that, if the line is a separate one, and not the ghât-section of a longer railway, the question of rack *versus* adhesion is simply one of cost of working.

Cost of Working.—A general idea of the cost of working a metre-gauge railway in India, and of the laws of variation in the working expenses according to the amount of business done, may be obtained by reference to Table V. (Appendix), which has been extracted from the "Administration Report on the Railways in India," for the year 1900. The results have been plotted graphically in *Figs. 3*, in which the abscissas represent the average number of trains daily each way which pass over any mile of the railway in question, and the ordinates represent the average yearly working expenses per mile under the different heads.

Engineering.—Excluding a few apparently abnormal cases, the plotted results agree fairly well with the straight line $Y = 280\ X$, with a probable minimum of $Y = 500$. If the line $Y = 280\ X$ be taken as representing the law of variation of working expenses in "Engineering," then, since it passes through the origin, the

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working expenses will vary with the train-mileage. Any law of this description is, of course, not true for any small and temporary

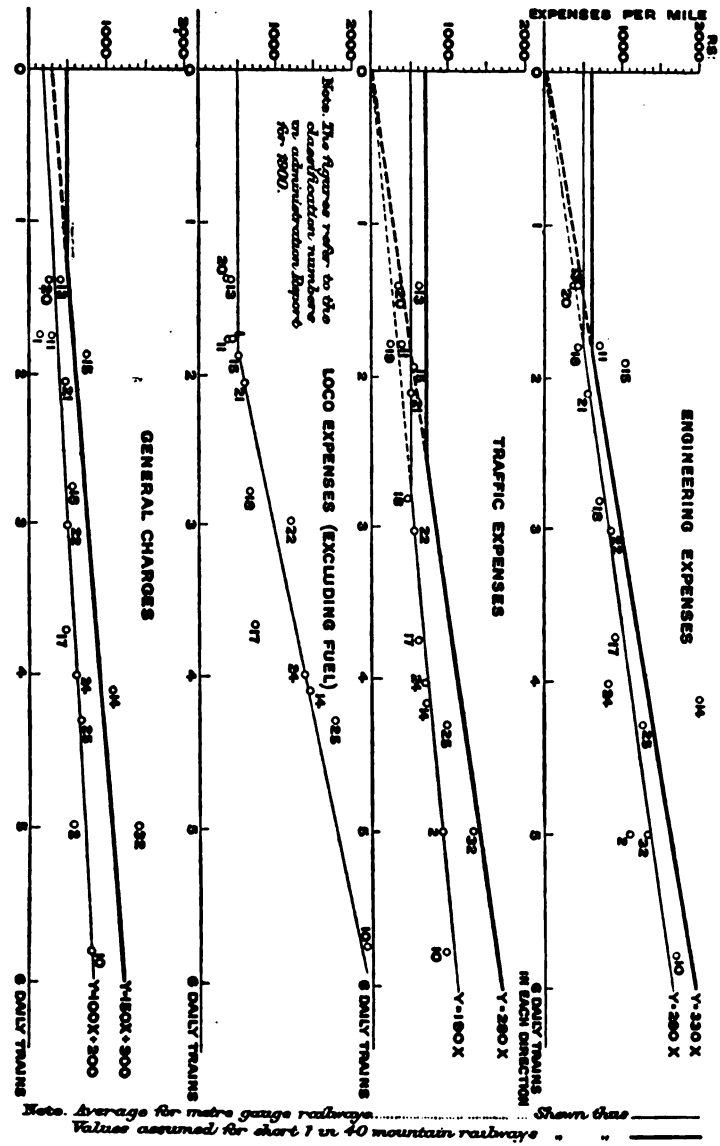

Fig. 3.

changes in the train-mileage of a railway. It is probable, however, that, for a permanent regime, the working-expenses will

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ultimately follow some law of this description, subject, of course, to variation in the constant for different railways, due to local conditions, such as high wages, etc. The length of the line will also affect the constant. There are many reasons[1] why maintenance-charges should not vary as the train-mileage, but the fact remains that they do, as is indicated in *Figs. 3*. This fact has also been noticed with regard to American railways, viz., that the maintenance expenses are much more nearly constant per train-mile than they are per mile of line[2]. The explanation of this may probably be found in the fact that, on a normal railway, a growth of traffic is coincident with an increase in the age of the line. The maintenance expenses per mile of line are probably intimately affected by the age of the line, as well as by the amount of traffic carried; although the amount of traffic is probably the most important factor, as a much higher standard of maintenance is required on a busy line than on a line running, say, only one or two trains per day. Any formula for maintenance-cost should therefore more properly contain at least two variables, the traffic carried and the age of the line. It is not, however, suggested that the working-expenses of a railway can be reduced to a simple mathematical formula, applicable to all cases. In plotting the results in *Figs. 3* it was only intended to obtain a general idea of the cost of working actual railways relatively to the amount of business done. It is possible, and indeed probable, that, for any particular railway, the lines plotted in *Figs. 3* should not be straight lines at all, but broken and irregular curves. The straight-line formulas quoted are taken as being simple in application and as fitting the actual results accurately enough for the purposes of an estimate. It will be understood that the formulas will only apply to normal railways, which begin by carrying a small traffic which increases and develops with the age of the line. Thus, for example, if a new railway starts off with six trains per day, the maintenance expenses will be much less to begin with than the formula would indicate; but they will increase, and ultimately approach those given by the formula as time goes on and the permanent-way, bridges, buildings, etc., begin to deteriorate. Another reason for the maintenance-charges being more or less constant per train-mile is that railway managers endeavour to

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[1] See "The Economic Theory of the Location of Railways," by A. M. Wellington, Chap. V., London, 1887; Spon.

[2] Ibid, Chap. V., par. 125, and Chap. XV., par. 717 and 718.

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suit their expenses to their receipts, and only spend money when justified in doing so by the amount of the traffic earnings. For short lines with heavy gradients, such as are now being considered, about 20 per cent. might be added to the constant, making the equation, say, $Y = 330\,X$, subject to a minimum of $Y = 600$.

In comparing the lines in the foregoing example, it will be fair to divide the annual expenditure on "Engineering" under (1) General Superintendence, and (2) Maintenance and other charges. In the case of the Darjeeling-Himalayan Railway the expenditure on General Superintendence is about one-third of the whole. For the 1-in-40 gradient, therefore, the length being 45·44 miles, the yearly charge for the whole line for "Engineering" will be

$$Y = (110 \times 45{\cdot}44 + 220 \times 45{\cdot}44)\,X,$$

$$\text{or } Y = 5{,}000\,X + 220 \times 45{\cdot}44\,X,$$

subject to a minimum of $600 \times 45{\cdot}44$; and for the other gradients of 1 in 8, 1 in 12½, and 1 in 25, it will be fair to consider the General Superintendence as independent of the length, and the same as for the 1-in-40 line, the balance to vary as L, the length of the line. That is, the total yearly charge for "Engineering" may be taken as

$$Y = 5{,}000\,X + 220\,L\,X,$$

subject to a minimum of $9{,}100 + 400\,L$, where L is the length of the line. In the case of rack-lines, the total maintenance expenses should be doubled,[1] and the yearly charge taken as $10{,}000\,X + 440\,L\,X$, subject to a minimum of $18{,}200 + 800\,L$.

Traffic.—The plotted results agree fairly well with the equation[2] $Y = 190\,X$, subject to a minimum of, say, $Y = 500$. Owing to the short length of the 1-in-40 gradient, and the consequent comparatively short lead of the goods, and also on account of the comparatively large number of crossing-stations on a mountain line, about 50 per cent. should be added to this, giving, say, $Y = 280\,X$, subject to a minimum of, say, $Y = 750$. In the case of traffic expenses, it will be fair to assume the total yearly charge per daily train to be the same for all gradients, and equal to the traffic expenses, as calculated for the 1-in-40 gradient.

[1] This really puts the rack-lines at a disadvantage, as experience goes to show that, after the embankments, etc., of a railway have become properly consolidated, there is little or no extra cost in maintenance due to the rack.

[2] This equation is more probably of the form $Y = Ax + B$, but the plotted results agree sufficiently well with the equation $Y = Ax$, and this form has been adopted, being simpler.

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Locomotives, and Carriages and Wagons.—Locomotives on mountain railways work under quite different conditions from those working on the plains on undulating gradients. Going up-hill is one continuous drag, and the engine has to be kept working up to its full power. In this comparison it will therefore be safest to take the Darjeeling-Himalayan Railway as a guide, as details of locomotive working on other mountain railways are not available in the Indian Railway Administration Reports.

On page 363 of the Administration Report for 1900, the following figures are given as the yearly working expenses of the Darjeeling-Himalayan Railway:—

	Rupees.
(*a*) General superintendence of locomotive and carriage and wagon	12,399
(*b*) Wages of running-staff	31,461
(*c*) Water	845
(*c*) Oil, etc.	7,257
(*c*) Repairs and renewals of locomotives	35,065
(*d*) Other charges	26,658 [1]
(*e*) Repairs, etc., locomotive and carriage and wagon	59,818

of these (*a*) might be taken as a mileage rate for the 1-in-40 gradient, and the same total yearly charge assumed for the other gradients; (*b*) is probably approximately proportional to the number of engines in service; while $(c + e)$ may be considered as proportional to the train-mileage. With regard to (*d*) probably a train-mileage rate will give the best results.

The Darjeeling-Himalayan Railway has fourteen engines in service, with a yearly train-mileage of 188,000 train-miles, the length of the line being 51 miles, with an average of five trains per day each way.

Therefore

$$(a) \quad = \frac{12,399}{51} = \text{say } 240 \text{ rupees per annum per mile of line.}$$

$$(b) \quad = \frac{31,461}{14} = 2,250 \text{ rupees per annum per engine.}$$

$$(c + e) = \frac{102,985}{188,000} = 0{\cdot}55 \text{ rupee per annum per train-mile.}$$

$$(d) \quad = \frac{26,658}{188,000} = 0{\cdot}14 \text{ rupee per annum} \quad ,,$$

For the purposes of the present investigation (*b*) seems somewhat too low, while $(c + e)$ would seem to be about right; on the broad-gauge lines in India $(c + e)$ is about 0·30 per train-mile.

[1] This figure should be 16,374, or about 0·09 per train-mile, but as the item is a small one, it is not thought worth while to alter the Tables.

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The following figures might be assumed for all the gradients, X being the number of trains daily:—

(a) must reasonably be made to vary to a certain extent with the number of daily trains, and might perhaps be taken as 8,000 + 800 X.

(b) = 4,000 rupees per annum per engine.

($c + e$) = 0·55 rupee per annum per train-mile for adhesion-lines, and 0·80 rupee per annum per train-mile for rack-lines and for adhesion-lines with Fairlie engines.

(d) = 0·14 rupee per annum per train-mile in all cases.

Fuel.—The subject of consumption of fuel requires special treatment on a mountain railway, and the only rational way of estimating it would appear to be on the basis of consumption per effective horse-power-hour. An engine working with about 30 lbs. of steam per HP.-hour (when C = 8)[1] would consume about 4 lbs. of good coal per HP.-hour. As C varies inversely as the steam-consumption (other things being equal), the coal-consumption in any case will be roughly $\left(4 \times \frac{8}{C}\right)$ lbs. per HP.-hour. For engines of Classes A and B, and for rack-engines, this would give about 7, and for engines of Classes C and D about 6 lbs. per HP.-hour. It will probably be sufficiently accurate to take an all-round figure of 7 lbs. per HP.-hour. This is probably a somewhat too liberal allowance, but it must be remembered that ordinary working conditions are being considered, and not special trials, and it is advisable to be on the safe side for estimate purposes.

The following is the method calculating the value of the fuel consumed:—

Taking, for example, an engine of class C on the 1-in-25 gradient, the engine is supposed to travel at 9 miles per hour and to develop 5·7 effective horse-power. $W_e = 5{\cdot}7 \times 55 = 313$ HP., Table III. (Appendix).

Consumption per hour (7 × 313)	2,191 lbs.
Duration of trip, $\frac{28{\cdot}40}{9}$	3·15 hours.
Consumption per trip (2,191 × 3·15)	6,910 lbs.
Allowed for downhill journey, at 200 lbs. per hour .	600 ,,
Added for standing idle, 5 hours at 40 ,, ,, .	200 ,,
Added for lighting up and drawing fire	1,000 ,,
Total consumption per double trip = 8,710 lbs. . .	3·88 tons.
Yearly consumption per daily train	1,417 ,,
At 15 rupees per ton.	21,300 rupees.

Similarly for the other cases.

[1] See page 230.

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General Charges.—This is a very uncertain quantity, as it will of course depend greatly upon whether the line is managed as a separate concern or in conjunction with another railway. As an arbitrary assumption, let $Y = 150\,X + 300$ for the 1 in-40 gradient, and let the total yearly amount be the same for the other gradients.

Total yearly charge $= 45{\cdot}44\,(150\,X + 300) = 6{,}800\,X + 13{,}500$, subject to a minimum of $500 \times 4{,}544 = 22{,}700$.

Tables VI. A, B and C (Appendix), have been constructed by calculating the working-expenses, as indicated in the foregoing. The total cost of carrying 1 ton of goods from the bottom of the line to the top has been worked out for the different gradients with the different classes of engine assumed. No absolute conclusions applicable to all cases can of course be drawn, as it is useless to generalize, and every case must be considered on its own merits. The example worked out is only intended as an illustration of a method which should be applied to every case of a mountain railway before deciding what gradient to adopt. In applying the method, the first thing to be done is to obtain from the Engineers reconnaissance-surveys and estimates showing the approximate profiles and the cost on different gradients. The next step is to obtain in detail the probable working-expenses under "Engineering," "Locomotive," "Traffic," and "General Charges," from expert officers in the departments concerned. After deciding on the weight of rail to be used and the limiting axle-load to be allowed, all the data required are known. Supposing in the present example that a line can be got on any of the gradients noted at an average cost of $1\frac{1}{2}$ lakh of rupees per mile, the approximate total average cost per ton, up and down hill, including interest on capital, is shown in Table VII. (Appendix). For a yearly traffic of less than 40,000 tons the 1-in-$12\frac{1}{2}$ rack would appear to be much the cheapest investment. For a traffic exceeding 40,000 tons and less than 60,000 tons, the 1-in-$12\frac{1}{2}$ rack still retains the advantage, but there is little difference between it and the 1-in-25 adhesion-gradient. The latter would probably be the better line to work between a traffic-capacity of 40,000 tons and one of 160,000 tons per annum. The 1-in-40 line would be the more expensive to work in all cases.

Although no absolute conclusions can be arrived at from this example which will be applicable to any given case, it is thought that something can be learnt in a general way. As the figures taken for working-expenses have not been taken at random, but have some kind of justification as representing average conditions, they are probably not very far wrong in any particular instance.

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This being the case, it appears probable that where a more or less continuous ruling-gradient is obtainable, and when the traffic is likely to be considerable, the line that is likely to pay the best dividends is the shortest line obtainable with adhesion-gradients, up to a limit of 1 in 25. Where the traffic is never likely to exceed 40,000 tons per annum, and more or less continuous rack-gradients up to a limit of 1 in 12½ are obtainable, this will probably give the cheapest line to work. Where the country is such that only a comparatively small portion of rack-line would be required, the question would have to be worked out in detail whether it would pay to develop for an adhesion-gradient, or to work it on the combined rack-and-adhesion system. When the line under consideration is not a separate undertaking, but the ghât section of a longer line, then questions of transhipment, pusher-engines, etc., occur, and the matter becomes somewhat more complicated. One other point is clearly brought out, viz., for any given gradient the working-expenses per ton of freight diminish as the load hauled per engine increases, showing the importance of heavy loads and consequent low speeds, in spite of the decrease in efficiency of the locomotive. The importance of introducing special supervision over the loading of the goods, so as to raise the value of m (Table III., Appendix)—which might be called the "coefficient of loading"—and thus reduce the average number of trains required to carry the same quantity of goods, is also clearly indicated in Tables VI., A, B and C (Appendix).

In Table VIII. are shown the approximate working-expenses per train-mile on the various gradients of the particular example, and also the proportion of expenses under the different heads to the total expenses. It will be seen that the cost per train-mile on a 1-in-12½ gradient is 7·94 rupees against 3·43 rupees on a 1-in-40 gradient. As the net average train-load on the 1-in-40 gradient is 45 tons, against 27 tons on the 1-in-12½ gradient (Table III., Appendix), giving 4¾ annas and 1¼ anna per ton-mile on the 1-in-12½ and 1-in-40 gradients respectively, it would appear at first sight as if the 1-in-40 line must be the better line. A consideration of Tables VI. and VII. (Appendix) will show how wrong this conclusion would be. The problem is not "what will be the working expenses per ton-mile of goods?" but "what will be the cost of transporting 1 ton of goods from one place to another at a different level, after taking the capital cost of the line into account?" For this reason mileage-rates have been carefully excluded from Tables VI. and VII. (Appendix). It will be observed that on mountain gradients the cost of fuel amounts to a large fraction of

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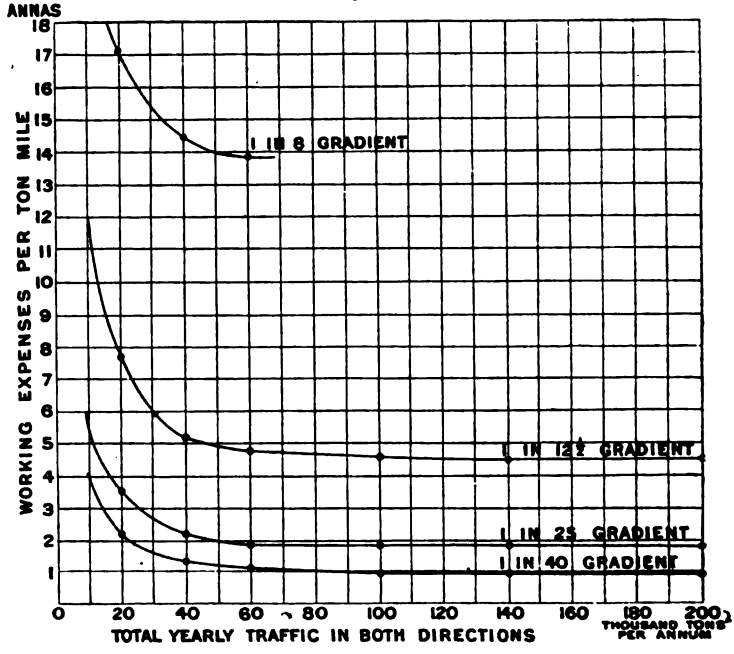
the total working-expenses. The importance of considering the fuel question in all its aspects, and of obtaining the best fuel (that is, the fuel which will do the work most cheaply) is indicated.

The cost per ton-mile of freight will probably not vary to any very great extent from the figures for the particular example for any railways on which there is a considerable proportion of maximum gradient, even if the railway is not wholly uphill in one direction.

The working-expenses per ton-mile for the different gradients, as derived from columns 2 and 8 of Table VII. (Appendix), are

Fig. 4.



plotted in *Fig. 4*, and these may perhaps be taken as giving a good general idea of the relative cost of working railways of different ruling-gradients, provided at least, say, one-half of the line is on the ruling gradient. It must, however, be borne in mind that it is not sufficient to know the cost per ton-mile, but that the length and the capital cost of the line must also be taken into account, as already pointed out.

Rolling-Stock.—It is obvious that, on a mountain railway, every care must be taken to secure that the ratio of the carrying-capacity

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to the tare-weight of each vehicle may be as high as possible. The following figures for passenger carriages are taken from *Engineering* of 30 December 1892, 16 November 1894, and 8 May 1896.

PASSENGER CARRIAGES FOR STEEP GRADIENTS.

Name of Railway.	Gauge.	Maximum Gradient.	Weight of Carriage.	Number of Passengers.	Passengers carried per Ton.
	Ft. Ins.	Per Cent.	Tons. Cwt.		
Rothhorn	2 7½	25	4 11	48	10·6
			5 2	48	9·4
Glion-Naye . . .	2 7½	..	5 8	48	8·9
Snowdon	2 7½	..	5 11	56	10·0
St. Gall and Gais . .	3 3⅜	9·2	7 2	32	4·5
Almatt Pass . . .	4 8½	5·0	8 10	50	5·9
Brünig Pass . . .	3 3⅜	12·0	7 10	36	4·8
Appenzell	3 3⅜	8·7	7 10	32	4·1
Landquart-Davos . .	3 3⅜	4·5	6 10	38	5·85
Rorschach Heiden .	3 3⅜	9·0	7 0	30	4·5

It would appear that for very heavy rack-inclines and very low speeds, carriages ought to carry about ten European passengers per ton of their tare-weight; and, for adhesion- or lighter rack-inclines with flat adhesion sections and relatively high speed thereon, they ought to carry about five or six passengers per ton of weight.

With regard to goods-wagons, every endeavour should of course be made to keep down their tare-weight, by the use of pressed steel or steel tubular underframes, etc. The ratio of paying-load to tare-weight should approximate to 4 to 1 in the case of open trucks and 2½ to 1 in the case of covered wagons.

Locomotives for Mountain Railways.—A locomotive of the ordinary type is a very efficient engine if run at a comparatively high speed, say, 30 miles an hour. At that speed one horse-power can be produced with about 30 lbs. of steam per hour or even less, or 20 to 25 HP. per square foot of grate-area. At low speeds, however, the case is very different. At piston-speeds corresponding to, say, 5 miles per hour, the condensation in the cylinder is very great, and as much as 60 lbs. of steam is used per HP.-hour. The results of some trials are shown in *Fig. 5*. These trials were made by attaching different loads to an engine and running it up 5 miles of continuous 1-in-40 gradient at as great a speed as the boiler could supply steam for, without unduly forcing the fire. The consumption of steam being so great at low speeds, it follows that,

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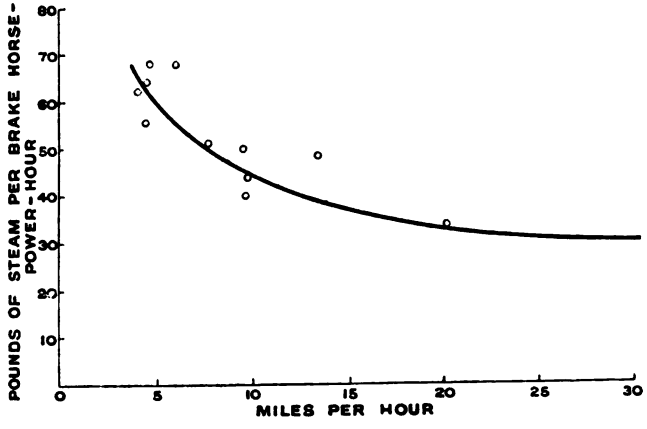
from the same engine, the horse-power which can be obtained at 5 miles per hour is only about half that which could be obtained at 30 miles per hour, and from actual engine performances it would appear that a horse-power amounting to about 8 times the weight of the engine in tons may be counted upon at a speed of 30 miles per hour. Working on this assumption, Table II. has been made out, the horse-power per ton of engine weight varying inversely as the consumption of steam shown in *Fig. 5.* For tank-engines the value of C will be relatively somewhat higher, since the weight of the coal-bunkers and water-tanks will necessarily be less than the weight of the tender, with its wheels, etc. Allowance has been made for this by increasing the value of C by $\frac{1}{8}$ for tank-engines.

Fig. 5.



Rack-engines must necessarily always travel at a low speed, as they cannot develop sufficient power to move a load corresponding to a tractive force of one-fifth of their weight at any speed exceeding 4 or 5 miles per hour. In most rack-engines, therefore, some device is resorted to, such as gearing down by means of levers or toothed wheels, to increase their piston-speed. This will tend to increase the value of C. On the other hand, there is increase of weight due to extra machinery. It is thought that some allowance should be made for an increase in the value of C, and in the Table C has been taken the same as for a tank-engine going at a speed 50 per cent. higher. Another reason for increasing the coefficient in the case of rack-engines is that, there being four cylinders, a better draught for the fire is obtained.

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It is evident that any device which would (*a*) increase the production of steam in the boiler, or (*b*) diminish its consumption by the engine, thus raising the value of the coefficient C, would increase the efficiency of the engine for mountain climbing.

(*a.*) The first steps towards the attainment of the former of these objects would seem to be: (i.) an enlargement of the grate-area, accompanied by an increase in the heating-surface by the employment of water-tubes in the fire-box; (ii.) the use of liquid fuel wherever procurable at less than, say, twice the cost of good coal; and (iii.) the adoption of water-tube boilers, when the character of the feed-water will allow of their use.

(*b.*) A decrease in the consumption of steam can be obtained (i.) by the use of compound engines, which use less steam at low piston-speeds; and (ii.) by gearing down the engine, to obtain increased piston-speed.

The quality of the fuel is of course a very important factor in the performance of any engine, and more particularly is this the case with a mountain locomotive. The stoking of a 60-ton engine, like one of those assumed, is very hard work, and, moreover, the performance of the engine is in the hands of the stoker—an important point in India, with native stokers. This is a very practical difficulty, and the best way of overcoming it satisfactorily would appear to be by the use of liquid fuel, if it can be obtained at any reasonable price.

The Paper is accompanied by four diagrams, from which the Figures in the text have been prepared, and by the following Appendix.

[APPENDIX.

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APPEN

TABLE I.—PARTICULARS

1	2	3		4	5	6	7	8	9
Name of Railway.	System.	Gauge.		Cost of Construction per Mile.	Radius of Sharpest Curve.	Steepest Gradient.	Length of Incline.	Diameter of Cylinder, etc.	Stroke.
		Ft.	Ins.	£.	Feet.		Miles.	Inches.	Inches.
1. New South Wales	Adh.	4	8½	..	..	1 in 40	..	20	26
2. St. Gothard . .	,,	4	8½	69,000	983	1 ,, 37	..	15¾ & 22¾	25½
3. Darjeeling. . .	,,	2	0	4,575	70	1 ,, 28	40	11	14
4. La Guaira-Caracas, Venezuela .	,,	3	0	25,000	240	1 ,, 27	23	15½	20
5. Mexican . . .	,,	4	8½	..	328	1 ,, 25	14	16	22
6. Callao-Oroya, Peru	,,	4	8½	32,000	394	1 ,, 25	100	18	24
7. Landquart-Davos.	,,	3	3⅜	11,520	328	1 ,, 22·2	13·7	19·3 & 13	21·7
8. Yverdon-Ste. Croix	,,	3	3⅜	..	328	1 ,, 22	..	11 & 16¾	19¾
9. Hartz	Adh. & Abt	4	8½	..	656	1 ,, 16·6	4	17·7 A. 11·82 R.	23·62 A. 23·62 R.
10. Mostar-Serajevo, Bosnia . . .	,,	2	6	..	410	1 ,, 16·6	12	13⅜ A. 11⅞ R.	17¾ A. 14½ R.
11. Tiadaghton-Fahnastalk, Pa, U.S.A.	Adh.	4	8½	..	191	1 ,, 16·6	..	12[2]	10
12. Madison, and Indianapolis . . .	,,	4	8½	..	..	1 ,, 16·5	1⅓	20½	24
13. Rimutaka, N.Z. .	Fell	3	6	28,160	330	1 ,, 15	2½	14 A. 12 F.	16 A. 14 F.
14. Eisenerz, Styria .	Adh. & Abt	4	8½	45,160	590	1 ,, 14·7	9	18·9 A. 16·5 R.	19·7 A. 17·7 R.
15. Puerto Cabello-Valencia, S.A. .	Abt	3	6	..	410	1 ,, 12·5	2½	11½ A. 11¼ R.	18
16. Oertelsbruch, Saxe Meiningen . .	Adh. & Abt	4	8½	..	492	1 ,, 12·5	1	11·8	19·7 A. 15·7 R.
17. Cantagallo, Brazil	Adh.	3	7⅜	20,000	131	1 ,, 12	6½	18	20
18. Pike's Peak, Colorado	Abt	4	8½	11,400	377	1 ,, 4	8·75	17	20
19. Usui, Japan . .	Adh. & Abt	..		..	..	1 ,, 15	..	15·3 A. 13·4 R.	19·7 A. 15·7 R.
20. Hollen Thal . .	Adh. & Rigg	4	8½	28,800	..	1 ,, 18·0	7	14·0 A. 12·4 R.	21·66 A. 19·69 R
21. St. Gall and Gais.	Adh. & Abt	3	3⅜	..	98·4	1 ,, 10	..	14·16 A. 14·16 R.	15·17
22. Nilgiri	,,	..		..	..	1 ,, 12·5	..	..	..

C = Coupled. [2] Coupled in threes. [3] 3 Coupled and 1 Bissel.

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DIX.

OF MOUNTAIN RAILWAYS.

10	11	12	13	14	15	16	17	18	19	20	21	22	23
Axles, Number.	Rigid Wheel-Base.	Diameter of Wheels.	Heating-Surface.	Engine Weight (Loaded).	Gross Train Load.	Speed, Miles per Hour.	HP. developed at Periphery of Driving-wheels.	IHP. per Square Foot of Heating-Surface.	HP. per Ton of Engine Weight.	Indicator-HP. per Sq. Ft. of Heating Surface, adding 15 Per Cent. for Adhesion and 25 Per Cent. for Rack.	Coefficient of Traction = K, derived from Actual Loads Hauled.	Grate-Area.	Type of Engine.
	Ft. Ins.	Ft. Ins.	Sq. Ft.	Tons.	Tons.							Sq.Ft.	
5[a]	13 10	5 0	1,922	56·75 / 31·75	275	10	660	0·34	7·46	0·39	$\frac{1}{8·1}$	..	Tender.
6[a]	8 10	4 0	1,660	84	200	10	543	0·33	6·48	0·38	$\frac{1}{9·2}$	..	Tank. Mallet comp.
2 C	5 6	2 2	355	13·75	35	8	95	0·27	6·9	0·31	$\frac{1}{6·9}$	8·7	Tank.
4[a]	6 10	3 0	872	33·75	68	8·7	223	0·25	6·60	0·29	$\frac{1}{7·9}$	..	Tender.
6[a]	8 3	3 6	1,712	92·25	175	8·5	612	0·36	6·64	0·41	$\frac{1}{7·7}$	..	Fairlie.
..	14 9	4 1	1,066	65	75	8·3	314	0·29	4·83	0·33	$\frac{1}{10·3}$	..	Tender.
4[a]	5 3	3 3	863	40	70	8	264	0·31	6·6	0·36	$\frac{1}{7·3}$	..	Tank. Mallet comp.
4[a]	4 7	3 3½	731	34	60	..	..	..	..	..	$\frac{1}{7·3}$	..	,,
4[a]	10 0	4 1	1,463	56	120	5	343	0·24	6·12	0·30	$\frac{1}{4·9}$	..	Tank.
4[a]	7 8	2 7½	763	30·5	70	5	196	0·26	6·40	0·32	$\frac{1}{4·7}$	..	,,
4[a]	4 2	..	..	35	75	5	215	..	6·13	..	$\frac{1}{4·9}$	..	Shay geared.
4 C	16 0	3 6	1,378	50	137½	6	440	0·32	8·80	0·37	$\frac{1}{4·1}$	..	Tank.
3 C	..	2 8	974	36	63	5	213	0·22	5·90	0·28	$\frac{1}{5·1}$	..	,,
4[a]	11 5	3 5	1,560	59	110	6	444	0·28	7·52	0·35	$\frac{1}{4·8}$	..	,,
3	8 9	3 6A. / 2 2R.	1,167	40·3	67	5	278	0·23	6·77	0·29	$\frac{1}{4·4}$	..	,,
3[a]	6 6¾	2 11½	517	23·2	50	5	186	0·36	8·04	0·45	$\frac{1}{3·7}$	..	,,
3 C	8 3	3 3	..	40[b]	40	5	212	..	5·30	..	$\frac{1}{5·7}$	..	Tender.
3	..	2 1½	..	23·8	18·7	3·1	202	..	8·48	..	$\frac{1}{2·2}$	..	Tank.
..	..	..	807	33·45	65	4·7	200	0·25	5·98	0·31	$\frac{1}{4·7}$	18·5	,,
3 C	11 6	3 6½	910	42	100	6·2	307	0·34	7·30	0·42	$\frac{1}{5·1}$	14·7	,,
2 C	10 2	2 7½	1,011	34·6	50	5	268	0·27	7·75	0·34	$\frac{1}{3·9}$	15	,,
..	..	..	750	33	45	4	158	0·21	4·82	0·26	$\frac{1}{5}$	..	,,

[a] Coupled in pairs. [b] Including weight of Tender 16·7 tons.

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TABLE III.—TABLE OF ESTIMATED LOADS AND SPEEDS AT WHICH THEY CAN BE HAULED FOR DIFFERENT CLASSES OF ENGINES ON DIFFERENT GRADIENTS; ALSO THEORETICAL TRAFFIC-CAPACITIES ON DIFFERENT GRADIENTS.

Gradient.	1 in 8.					1 in 12½.					1 in 25.					1 in 40.				
Length of Line.	9·08 miles.					14·20 miles.					28·40 miles.					45·44 miles.				
Class of Engine.	A.	B.	C.	D.	Rack	A.	B.	C	D.	Rack	A.	B.	C.	D.	Rack	A.	B.	C.	D.	Rack
Probable weight of engine (and tender) tons	75	60	55	68	60	75	60	55	68	60	75	60	55	68	60	75	60	55	68	60
Weight on drivers . . . . . ,,	60	60	40	40	..	60	60	40	40	..	60	60	40	40	..	60	60	40	40	..
Value of coefficient K	1/8·7	1/7	1/9·6	1/11·8	1/5	1/8·7	1/7	1/9·6	1/11·8	1/5	1/7	1/7	1/9·6	1/11·8	1/5	1/8·7	1/7	1/9·6	1/11·8	1/5
Approximate gross train-load, limited by adhesion, from Eq. (4) . . . . tons	[1]	6	[1]	[1]	32	26	41	12	[1]	81	115	130	72	59	207	210	225	135	122	340
Approximate speed from Eqs. (6), (7), and (8)	..	..	..	..	4	..	..	..	..	4	7	5½	9	11	4	7	5½	9	11	4
Value of C from Table II.	..	..	..	..	4·8	..	..	..	..	4·8	4·6	4·7	5·7	5·5	4·8	4·6	4·7	5·7	5·5	4·8
Effective HP. = C W$_t$	..	..	..	..	288	..	..	..	..	288	345	282	313	374	288	345	282	313	374	288
Corrected load working up to HP. . . .	..	..	..	..	33	..	..	..	..	81	107	130	74	58	207	199	224	137	120	340
Assuming $m = \frac{1}{3}$, net train-load = m W$_t$.	..	..	..	..	11	..	..	..	..	27	36	43	25	19	69	66	75	46	40	113
Time between stations = $\frac{L}{N S}$ . . hours	..	..	..	..	0·30	..	..	..	..	0·30	0·30	0·30	0·30	0·30	0·30	0·30	0·30	0·30	0·30	0·30
Distance apart . . . . . miles	..	..	..	..	1·2	..	..	..	..	1·2	2·1	1·6	2·7	3·3	1·2	2·1	1·6	2·7	3·3	1·2
Stoppage at stations . . . . . hours	..	..	..	..	0·10	..	..	..	..	0·10	0·10	0·10	0·10	0·10	0·10	0·10	0·10	0·10	0·10	0·10
Number of trains per hour in both directions $= \frac{1}{\frac{L}{N S} + t}$	..	..	..	..	2·5	..	..	..	..	2·5	2·5	2·5	2·5	2·5	2·5	2·5	2·5	2·5	2·5	2·5
Traffic capacity, tons of freight per hour in both directions	..	..	..	..	27	..	..	..	..	67	89	107	61	47	172	165	186	114	100	282
Relative traffic capacity, taking a D class engine on 1 in 40 as 1·00	..	..	..	..	0·27	..	..	..	..	0·67	0·89	1·07	0·61	0·47	1·72	1·65	1·86	1·14	1·00	2·82

[1] Engine would not pull its own weight on the gradient.

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TABLE IV.—MAXIMUM NUMBER OF TRAINS IN EACH DIRECTION IT IS POSSIBLE TO RUN IN A WORKING DAY OF ABOUT 12 HOURS.

Number of Crossing Stations.	1 Crossing Station.					2 Crossing Stations.					3 Crossing Stations.					4 Crossing Stations.					5 Crossing Stations.				
Gradients.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.
1 in 8 .	..	..	..	..	8	..	..	..	..	4	..	..	..	..	6	..	..	..	..	8	..	..	..	..	8
1 in 12½ .	..	..	..	..	2	..	..	..	..	2	..	..	..	..	3	..	..	..	..	3	..	..	..	..	5
1 in 25 .	2	2	3	3	1	2	1	3	3	1	3	2	4	5	1	3	2	4	6	1	4	3	6	7	1
1 in 40 .	1	1	2	2	1	1	1	1	2	0	1	1	2	3	0	1	1	2	3	0	2	1	3	4	0

Number of Crossing Stations.	6 Crossing Stations.					7 Crossing Stations.					9 Crossing Stations.					11 Crossing Stations.					13 Crossing Stations.				
Gradients.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.	A.	B.	C.	D.	R.
1 in 8 .	..	..	..	..	8	..	..	..	..	1	..	..	..	..	1	..	..	..	..	1	..	..	..	..	..
1 in 12½	..	..	..	..	4	..	..	..	..	6	..	..	..	..	7	..	..	..	..	7	..	..	..	..	1
1 in 25 .	4	3	6	7	1	5	3	7	8	2	6	4	7	1	2	6	4	1	1	2	1	4	1	1	2
1 in 40 .	1	1	3	4	0	2	1	3	5	0	2	1	4	6	0	3	1	4	5	0	3	1	4	6	0

NOTE.—Maximum daily capacity of 1-in- 8 gradient = 8 × 22 = 176 tons paying freight.
" " 1-in-12½ " = 7 × 54 = 378 " " } In both directions.
" " 1-in-25 " = 6 × 71 = 426 " with an A class Engine.
" " 1-in-40 " = 6 × 80 = 480 " " a D "

[1] Minimum time allowable between stations assumed at about 20 minutes.

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TABLE IV. A.—MAXIMUM PRACTICAL TRAFFIC-CAPACITY OF THE DIFFERENT GRADIENTS.

	1 in 8.					1 in 12½.					1 in 25.					1 in 40.				
	A.	B.	C.	D.	Rack.	A.	B.	C.	D.	Rack.	A.	B.	C.	D.	Rack.	A.	B.	C.	D.	Rack.
Maximum traffic-capacity, tons per hour	..	..	..	..	7·3	..	..	..	..	15·5	17·5	14·3	14·3	12·7	11·5	16·5	6·2	15·1	20·0	Nil
Relative traffic-capacities, taking D class engine on 1 in 40 as 1·00 . .	..	..	..	..	0·36	..	..	..	..	0·79	0·88	0·71	0·71	0·63	0·58	0·82	0·31	0·76	1·0	Nil
Time taken to perform journey (including stops) in hours	..	..	..	..	3·07	..	..	..	..	4·35	5·86	6·96	4·56	3·98	9·80	8·69	11·06	6·85	5·93	13·36

NOTE.—The figures are obtained by multiplying twice the maximum number of daily trains as per Table IV., by the net train-load as given in Table III. and dividing by 24.

All these traffic-capacities require six to nine crossing stations.

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TABLE V.—WORKING EXPENSES OF METRE-GAUGE RAILWAYS.

Classification Number.[1]	Name of Railway.	Mean Mileage worked.	Train-Mileage.	Average Number of Daily Trains Each Way Passing any Point in the Line.	Yearly Maintenance Expenses per Mile of Track.	Yearly Traffic Expenses per Mile of Track.	Yearly Locomotive Expenses per Mile of Track.				
							Total Locomotive Expenses.	Total Carriage and Wagon Expenses.	Fuel.	Locomotive and Carriage and Wagon Expenses without Fuel.	General Charges.
		Miles.	Train-Miles.		Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.
13	Bengal-Dooars . . .	56	58,000	1·4	406	581	616	118	326	408	406
14	Dibru-Sadiya . . .	77	227,000	4·1	2,033	733	1,279	621	493	1,407	1,070
15	Assam-Bengal . . .	436	599,000	1·9	1,016	533	585	141	212	514	712
17	Bengal & North-Western	1,137	3,067,000	3·7	972	591	794	227	290	731	446
18	Rohilkund & Kumaon .	280	580,000	2·8	707	477	592	233	187	638	529
19	Jodhpur-Bikaner . .	472	627,000	1·8	406	214	773	96	415	454	127
20	Udaipur-Chitor . . .	67	66,000	1·4	392	319	734	62	457	339	262
21	Bhávnagar Gondal-Junágad-Porbándar .	455	685,000	2·1	560	494	836	160	407	589	447
22	Southern Mahratta .	1,595	3,493,000	3·0	841	577	1,183	331	335	1,179	501
23	West of India Portuguese	51	84,000	2·8	1,315	1,127	1,838	418	..	..	1,879
24	South India	1,110	3,254,000	4·0	837	707	1,481	466	610	1,337	601
25	Burma	1,084	3,415,000	4·3	1,264	942	2,096	498	840	1,754	632
32	Darjeeling-Himalayan[2]	51	188,000	5·0	1,373	1,353	2,941	1,275	1,020	3,196	1,431
12c.	Nilgiri	17	38,000	3·0	2,501	572	3,231	207	1,500	1,938	226
10 f. to i.	Rajputana-Malwa . .	1,837	7,771,000	5·8	1,733	953	2,651	763	1,270	2,144	570
11c.	Hyderabad - Gódávari Valley	340	457,000	1·8	711	376	756	51	386	421	294
2 b. to d.	Eastern Bengal . . .	627	2,259,000	5·0	1,159	940	1,063	395	..	..	455

[1] In "Administration Report on the Railways in India" for 1900.

[2] 2 feet gauge.

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TABLE VI. A.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-40 gradient, 45·44 miles.

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
A. Maintenance 330 X × 45·44	27,300	29,000	44,800	59,800	74,800	89,600	1,04,000	1,19,000
D. Traffic 280 X + 45·44	34,000	34,000	38,100	50,700	63,500	76,300	89,000	1,01,700
E. General charges (150 X + 300) 45·44 . . .	22,700	27,000	34,100	40,900	47,700	54,500	61,300	68,100
Total of above . . Rupees	84,000	91,200	1,17,000	1,51,400	1,86,000	2,20,400	2,54,300	2,88,800
LOCOMOTIVE AND CARRIAGE AND WAGON.								
A Class Engine.				Double engine.				
Average number of engines in daily service . .	2	4	6				..	..
Number of engines required	3	6	9	12	15	18	..	..
Train-mileage per year	33,000	66,000	99,000	132,000	165,000	198,000	..	..
General superintendence	8,000	9,600	10,400	11,200	12,000	12,800	..	..
Wages, etc., at 4,000 per engine	12,000	24,000	36,000	48,000	60,000	72,000	..	..
Repairs at 0·80 per train-mile	26,400	52,800	79,200	1,05,600	1,32,000	1,58,400	..	..
Other charges at 0·14 per train-mile	4,600	9,200	13,800	18,400	23,000	27,600	..	..
Fuel	44,300	88,600	1,32,900	1,77,200	2,21,500	2,65,800	..	..
B.—Total locomotive expenses . . Rupees	96,100	1,84,200	2,72,300	3,60,400	4,48,500	5,36,600	..	..
B Class Engine.								
Average number of engines in daily service same as before, therefore.	3	6	..	..	..	..	..	..
General superintendence, wages and repairs, etc.	51,800	95,700	..	..	..	..	..	..
Fuel	46,800	93,600	..	..	..	..	..	..
B.—Total locomotive expenses . . Rupees	98,600	1,89,200	..	..	..	..	..	..

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TABLE VI. A.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-40 gradient, 45·44 miles—*continued.*

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
C Class Engine.								
Average number of engines in daily service . .	1	2	6	8	..	..	..	..
Number of engines required	2	4	9	12	..	..	..	..
Train-mileage	33,000	66,000	99,000	1,32,000	..	..	..	..
General superintendence	8,800	9,600	10,400	11,200	..	..	..	..
Wages	8,000	16,000	36,000	48,000	..	..	..	..
Repairs at 0·55 per train-mile	18,000	36,000	54,000	72,000	..	..	..	..
Other charges	4,600	9,200	13,800	18,400	..	..	..	..
Fuel	32,300	64,600	96,900	1,29,200	..	..	..	..
B. Total locomotive expenses . . Rupees	71,700	1,35,400	2,11,100	2,78,800	..	..	..	..
DClass Engine.								
Average number of engines in daily service . .	1	2	4	6	8	12	..	..
Number of engines required	2	4	6	9	12	18	..	..
Train-mileage per year	33,000	66,000	99,000	132,000	165,000	198,000	..	..
General superintendence	8,800	9,600	10,400	11,200	12,000	12,800	..	..
Wages at 4,000 per engine	8,000	16,000	24,000	36,000	48,000	72,000	..	..
Repairs, etc., at 0·55 per train-mile	18,000	36,000	54,000	72,000	90,000	1,08,000	..	..
Other charges at 0·14 per train-mile	4,600	9,200	13,800	18,400	23,000	27,600	..	..
Fuel	31,300	62,600	93,900	1,25,200	1,56,500	1,87,800	..	..
B. Total locomotive expenses . . Rupees	70,000	1,33,400	1,96,100	2,62,800	3,29,500	4,08,200	..	..

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TABLE VI. A.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-40 gradient, 45·44 miles—*concluded.*

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
Total A, B, D and E.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.		
A Class engine	1,80,100	2,75,400	3,89,300	5,11,800[2]	6,34,500[2]	7,57,000[2]	..	..
B „ „	1,82,600	2,80,400[2]	..	..	..	..	..	..
C „ „	1,55,700	2,26,600	3,28,100	4,30,200	..	..	..	..
D „ „	1,54,700	2,24,600	3,13,000	4,14,200	5,15,500	6,28,600	..	..
Goods carried per Year.[1]	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.		
A Class engine	48,200	96,400	144,600	192,800	241,000	289,200		
B „ „	54,400	108,800	..	..	..	..	..	..
C „ „	33,200	66,400	99,600	132,800	..	..	..	..
D „ „	29,200	58,400	87,600	116,800	146,000	175,200	..	..
Cost of Carriage per Ton.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.		
A Class engine	3·74	2·86	2·70	2·66[2]	2·64[2]	2·62[2]	..	..
B „ „	3·35	2·58[2]	..	..	..	..	..	..
C „ „	4·68	3·41	3·29	3·24	..	..	..	..
D „ „	5·28	3·84	3·57	3·55	3·53	3·38	..	..

[1] The total tonnage of goods carried per year is equal to the net train-load as given in Table III. multipled by 365 and by the average number of daily trains *in both directions.*

[2] Double engine loads.

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TABLE VI. B.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-25 gradient—28·40 miles.

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
A. Maintenance (500 X + 220 × 28·40 X.) . .	20,500	22,600	33,900	45,200	56,500	67,800	79,100	90,400
D. Traffic	34,000	34,000	38,100	50,700	63,500	76,300	89,000	1,01,700
E. General charges	22,700	27,300	34,100	40,900	47,700	54,500	61,300	68,100
Total A D & E . . . Rupees	77,200	83,900	1,06,100	1,36,800	1,67,700	1,98,600	2,29,400	2,60,200
B. LOCOMOTIVE AND CARRIAGE AND WAGON.								
A Class Engine.								
Average number of engines in daily service . .	1	2	4	6	8	10	..	..
Number of engines required.	2	4	6	9	12	15	..	..
Train-mileage	20,600	41,200	61,800	82,400	1,03,000	1,23,600	..	..
General supervision	8,800	9,600	10,400	11,200	12,000	12,800	13,600	14,400
Wages at 4,000 per engine	8,000	16,000	24,000	36,000	48,000	60,000	..	..
Repairs, etc., at 0·80 per train-mile	16,480	32,960	49,440	65,920	82,400	98,880	1,15,360	1,31,840
Other charges at 0·14	2,900	5,800	8,700	11,600	14,500	17,400	20,300	23,200
Fuel	28,900	57,800	86,700	1,15,600	1,44,500	1,73,400	..	..
B. Total locomotive expenses . . Rupees	65,080	1,22,160	1,79,240	2,40,320	3,01,400	3,62,480	..	..

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TABLE VI. B.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-25 gradient—28·40 miles—*continued.*

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
B Class Engine.								
Number of engines required.	1	4	6	8	Double engine.			
Add 50 per cent.	2	6	9	12	15	18	21	24
General supervision and repairs and other charges	28,180	48,360	68,540	88,720	1,08,900	1,29,080	1,49,260	..
Wages at 4,000 per engine	8,000	24,000	36,000	48,000	60,000	72,000	84,000	..
Fuel	30,200	60,400	90,600	1,20,800	1,51,000	1,81,200	2,11,400	..
B. Total locomotive expenses . . Rupees	66,380	1,32,760	1,95,140	2,57,520	3,19,900	3,82,280	4,44,660	..
C Class Engine.								
Average number of engines in daily service . .	1	2	3	4	5	6	7	..
Number of engines required.	2	4	5	6	9	9	10	..
General supervision and repairs[1] and other charges	23,000	38,000	53,000	68,000	83,000	98,000	1,13,000	..
Wages at 4,000 per engine	8,000	16,000	20,000	24,000	36,000	36,000	40,000	..
Fuel	21,400	42,800	64,200	85,600	1,07,000	1,28,400	1,49,800	..
B. Total locomotive expenses . . Rupees	52,400	96,800	1,37,200	1,77,600	2,26,000	2,62,400	3,02,800	..

[1] Taking repairs at 0·55 per train-mile.

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TABLE VI. B.—WORKING EXPENSES, RUPEES PER ANNUM—*continued.*

1-in-25 gradient—28·40 miles—*continued.*

Average number of daily trains each way . .	1	2	3	4	5	6	7	8
D. Class Engine.								
Average number of engines in daily service . .	1	2	3	4	4	6	6	8
Number of engines required	2	4	5	7	7	10	10	12
General supervision, repairs and other charges .	23,000	38,000	53,000	68,000	83,000	98,000	1,13,000	1,28,000
Wages at 4,000 per engine	8,000	16,000	20,000	28,000	28,000	40,000	40,000	48,000
Fuel	20,500	41,000	61,500	82,000	1,02,500	1,23,000	1,43,000	1,64,000
B. Total locomotive expenses . . Rupees	51,500	95,000	1,34,500	1,78,000	2,13,500	2,61,000	2,96,500	3,40,000
Rack Engine.								
A. Maintenance—$y = 10,000\,x + 440\,\mathrm{L}\,x$ . .	40,900	45,000	67,500	90,000	..	..	..	..
D. Traffic	34,000	34,000	38,100	50,700	..	..	..	..
E. General charges	22,700	27,300	34,100	40,900	..	..	..	..
Total A, D and E . . Rupees	97,600	1,06,300	1,39,700	1,81,600	..	..	..	..
			Double engine					
Average number of engines in daily service . .	2	4			..	..	..	..
Number of engines required	3	6	9	12	..	..	..	..
Train-mileage	20,600	41,200	61,800	82,400	..	..	..	..
General supervision	8,800	9,600	10,400	11,200	..	..	..	..
Wages at 4,000 per engine	12,000	24,000	36,000	48,000	..	..	..	..
Repairs at 0·80	16,500	33,000	49,500	66,000	..	..	..	..
Other charges at 0·14	2,900	5,800	8,700	11,600	..	..	..	..
Fuel	41,200	82,500	1,23,600	1,64,800	..	..	..	..
B. Total locomotive expenses . . Rupees	81,400	1,54,700	2,28,200	3,01,600	..	..	..	..

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TABLE VI. B.—WORKING EXPENSES, RUPEES PER ANNUM—*continued.*

1-in-25 gradient—28·40 miles—*continued.*

Average number of daily trains each way [1]	1	2	3	4	5	6	7	8
Total A, B, D and E.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.
A Class engine	1,42,280	2,06,060	2,85,340	3,77,120	4,69,100	5,61,080	..	..
B " "	1,43,580	2,16,660	3,01,240	3,94,320	4,87,600[2]	5,80,880[2]	6,74,060[2]	..
C " "	1,29,600	1,80,700	2,43,300	3,14,400	3,93,700	4,61,000	5,32,200	..
D " "	1,28,700	1,78,900	2,40,600	3,14,800	3,81,200	4,59,600	5,25,900	6,00,200
R " "	1,79,000	2,61,060	3,67,900[2]	4,83,200[2]	..	..	..	..
Goods Carried.[1]	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
A Class engine	25,900	51,800	77,700	1,03,600	1,29,500	1,55,400	2,19,800	..
B " "	31,400	62,800	94,200	1,25,600	1,57,000	1,88,400	1,25,300	..
C " "	17,900	35,800	53,700	71,600	98,500	1,07,400	97,300	..
D " "	13,900	27,800	41,700	55,600	69,500	83,400	..	1,11,200
R " "	50,300	1,00,600	1,50,900	2,01,200	..	..	..	..
Average Rate per Ton.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.
A Class engine	5·49	3·97	3·67	3·64	3·62	3·61	..	..
B " "	4·57	3·44	3·20	3·14	3·11[2]	3·08[2]	3·06[2]	..
C " "	7·23	5·03	4·53	4·40	4·50	4·28	4·25	..
D " "	9·25	6·44	5·78	5·67	5·48	5·51	5·41	5·40
R " "	3·56	2·61	2·44[2]	2·41[2]	..	..	..	..

[1] The total tonnage of goods carried per year is arrived at by multiplying the nett train-load in Table III. by 365 and by the number of daily trains in both directions.

[2] Double-engine trains.

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TABLE VI. C.—WORKING EXPENSES, RUPEES PER ANNUM.

1-in-12½, rack, 14·20 miles.

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
A. Maintenance (10,000 + 440 L) X	29,560	32,500	48,750	65,000	81,250	97,500	1,13,750	1,30,000
D. Traffic	34,000	34,000	38,100	50,700	63,500	76,300	89,000	1,01,700
E. General charges	22,700	27,300	34,100	40,900	47,700	54,500	61,300	68,100
Total A, D and E . . . . Rupees	86,260	93,800	1,20,950	1,56,600	1,92,450	2,28,300	2,64,050	2,99,800
Average number of engines in daily service . .	1	2	4	5	5	7	10	..
Number of engines required	2	4	7	8	8	11	15	..
Train-mileage	10,300	20,600	30,900	41,200	51,500	61,800	72,100	..
General superintendence	8,800	9,600	10,400	11,200	12,000	12,800	13,600	..
Wages	8,000	16,000	28,000	32,000	32,000	44,000	60,000	..
Repairs at 0·80 per train-mile	8,200	16,400	24,600	32,800	41,000	49.200	57,400	..
Other charges	1,500	2,900	4,400	5,800	7,300	8,700	10,200	..
Fuel	22,200	44,400	66,600	88,800	1,11,000	1,33,200	1,55,400	..
B. Total locomotive expenses . . Rupees	48,700	89,300	1,34,000	1,70,600	2,03,300	2,47,900	2,96,600	..
Total A, B, D and E . . . Rupees	1,34,960	1,83,100	2,54,950	3,27,200	3,95,750	4,76,200	5,60,650	..
Goods carried . . . . . Tons	19,700	39,400	59,100	78,800	98,500	1,18,200	1,37,900	..
Average rate per ton . . . Rupees	6·85	4·64	4·32	4·15	4·02	4·02	4·07	..

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TABLE VI. C.—WORKING EXPENSES, RUPEES PER ANNUM—*continued.*

1-in-8, rack, 9·08 miles.

Average number of daily trains each way. . .	1	2	3	4	5	6	7	8
A. Maintenance	25,400	28,000	42,000	56,000	70,000	84,000	98,000	1,12,000
D. Traffic	34,000	34,000	38,100	50,700	63,500	76,300	89,000	1,01,700
E. General charges	22,700	27,300	34,100	40,900	47,700	54,500	61,300	68,100
Total A, D and E . . . . Rupees	82,100	89,300	1,14,200	1,47,600	1,81,200	2,14,800	2,48,300	2,81,800
Average number of engines in daily service . .	1	2	2	3	4	4	5	6
" " " required	2	4	4	5	7	7	8	10
Train-mileage	6,650	13,300	19,950	26,600	33,250	39,900	46,550	53,200
General superintendence	8,800	9,600	10,400	11,200	12,000	12,800	13,600	14,400
Wages	8,000	16,000	16,000	20,000	28,000	28,000	32,000	40,000
Repairs, etc.	5,300	10,600	15,900	21,200	26,500	31,800	37,100	42,400
Other charges	900	1,900	2,800	3,700	4,700	5,600	6,500	7,400
Fuel	15,400	30,800	46,200	62,600	77,000	92,400	1,07,800	1,23,200
B. Total locomotive expenses . . Rupees	38,400	68,900	91,300	1,18,700	1,48,200	1,70,600	1,97,000	2,27,400
Total A, B, D and E . . . Rupees	1,20,500	1,58,200	2,05,500	2,66,300	3,29,400	3,85,400	4,45,300	5,09,200
Goods carried . . . . . Tons	8,050	16,100	24,150	32,200	40,250	48,300	56,350	64,400
Average rate per ton . . Rupees	15·00	9·82	8·50	8·27	8·18	7·97	7·90	7·90

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TABLE VII.—TOTAL AVERAGE COST OF DELIVERING 1 TON OF GOODS FROM ONE END OF THE LINE TO THE OTHER, INCLUDING INTEREST CHARGES ON CAPITAL COST, ASSUMING THE CAPITAL COST PER MILE IN EACH CASE TO BE 1,50,000 Rupees.

Gradient.	Length of Line.	Capital Cost per Mile.	Total Capital Cost.	Interest on Capital Cost at 4 Per Cent.	Goods carried per Year.	Interest Charges per Ton of Goods.	Approximate Working Expenses per Ton.	Total Cost of Carriage per Ton of Goods.	Remarks.
						Rupees.	Rupees.	Rupees.	
1 in 8	9·08	1,50,000	13,60,000	54,400	20,000	2·72	9 75	12·47	Rack.
1 „ 12½	14·20		20,30,000	81,200		4·06	6·80	10·86	„
1 „ 25	28·40		42,70,000	1,70,800		8·54	6·45	14·99	B Class engine (small).
1 „ 40	45·44		68,20,000	2,72,800		13·64	6·10	19·74	D „ „
1 „ 8	„	„	„	„	40,000	1·36	8 18	9·54	Rack.
1 „ 12½						2·03	4·60	6·63	„
1 „ 25						4·27	4·15	8·42	B Class engine or rack.
1 „ 40						6·82	3·83	10·65	B Class engine.
1 „ 8	„	„	„	„	60,000	0·91	7·90	8·81	Rack.
1 „ 12½						1·35	4·27	5·62	„
1 „ 25						2·85	3·45	6·30	B Class engine.
							3·28	6·13	Rack.
1 „ 40						4·55	3·23	7·78	B Class engine.
1 „ 12½	„	„	„	„	1,00,000	0·81	4·02	4·83	Rack.
1 „ 25						1·71	3·15	4·86	B Class engine.
							2·61	4·32	Rack.
1 „ 40						2·73	2·78	5·51	B Class engine.
1 „ 12½	„	„	„	„	1,40,000	0·58	4·02	4·60	Rack.
1 „ 25						1·22	3·12	4·34	B Class engine.
							2·40	3·62	Rack.
1 „ 40						1·95	2·70	4·65	A Class engine.
1 „ 12½	„	„	„	„	2,00,000	0·40	4·00	4·40	Rack.
1 „ 25						0·85	3·06	3·91	A Class engine.
							2·41	3·26	Rack.
1 „ 40						1·36	2·66	4·02	A Class engine.

NOTE.—The working expenses per ton are the average of uphill and downhill journeys.

This Table shows a saving in working expenses on the 1-in-25 gradient by adopting the rack system. The difference is, however, small, and would probably be swallowed up by the interest on the capital cost of the rack itself.

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TABLE VIII.—APPROXIMATE WORKING EXPENSES PER TRAIN-MILE ON VARIOUS GRADIENTS WHEN THERE IS AN AVERAGE DAILY TRAFFIC OF ABOUT 200 TONS PER DAY PASSING OVER ANY MILE OF THE LINE.

Heads of Account.	1 in 40. C Class Engines.		1 in 25. A Class Engine.		1 in 12½. Rack Engines.		1 in 8. Rack Engine.	
	Working Expenses per Train-Mile.	Per Cent. of Total Working Expenses.	Working Expenses per Train-Mile.	Per Cent. of Total Working Expenses.	Working Expenses per Train-Mile.	Per Cent. of Total Working Expenses.	Working Expenses per Train-Mile.	Per Cent. of Total Working Expenses.
	Rupees.	Per Cent.	Rupees.	Per Cent.	Rupees.	Per Cent.	Rupees.	Per Cent.
Maintenance	0·45	13	0·55	12	1·58	20	2·11	22
Traffic	0·51	15	0·61	13	1·23	15½	1·91	20
Locomotive and carriage and wagon (excluding fuel)	1·07	31	1·50	33	1·98	25	1·96	20
Fuel	0 98	29	1·40	30	2·16	27	2·32	24
General charges	0·42	12	0·55	12	0·99	12½	1·28	14
Total	3·43	100	4·61	100	7·94	100	9·58	100

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(Paper No. 3376.)

"The Burnett and Kennedy Bridges, Bundaberg, Queensland."

By ALFRED JOSEPH GOLDSMITH, M. Inst. C.E.

THE town of Bundaberg, on the Burnett River, in Queensland, is the centre of a large sugar-producing district, and is a notable example of the rapid growth of colonial townships, having been founded as recently as 1871. The two steel bridges described in the following Paper, which were erected by the Public Works Department of Queensland during 1898–1900, together with the large steel bridge carrying the main line of railway to the north, which spans the Burnett River immediately above the site of the new traffic-bridge, have added greatly to the appearance of the town and to its progressive aspect.

THE BURNETT BRIDGE.

The main township is on the south bank of the river, but with the formation of extensive plantations in the districts lying to the north, at Fairymead, Gin Gin, Bingera, Kolan River, etc., the establishment of a considerable mining industry in copper and gold at Mount Perry, some 60 miles distant, and also the occupation of the country between Bundaberg and Gladstone for homesteads, cattle-stations, etc., a considerable traffic across the river, which is about 800 feet in width at this part, has developed. The Burnett crossing affords an interesting example of the progressive development of the means of communication across tidal rivers in new countries. The first facilities provided were in the form of an oblong punt of wood pulled across the river by hand-labour. These facilities were greatly improved about 13 years ago, under the auspices of a Board of representatives from the local Authorities interested, by the provision of the iron ferry-punt "Transit," (Figs. 4, Plate 6), designed and built by the Author at Maryborough, and towed by sea to the site of the ferry.

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The engines had two cylinders, 6 inches in diameter by 10 inches stroke, working at a pressure of 75 lbs. per square inch and driving the hauling-wheel of the rope-gear, 4 feet 6 inches in diameter, through mortice spur-gear. A speed of 500 feet per minute could easily be maintained in crossing, and the ferry worked noiselessly and economically. A sponson on one side of the punt provided accommodation under cover for foot-passengers, apart from the horse, cattle and vehicular traffic. The ferry was worked upon a hard-laid Manilla rope, 6 inches in circumference, specially manufactured for the purpose at the Kangaroo Point Rope Works, Brisbane, at a cost of about £30 per rope, which lasted, on an average, about 7 months in constant work. The fuel was cord-wood cut to 4-foot lengths. On the initiative of the local Authorities more immediately interested, a Bill was passed through the Queensland Parliament in 1889, authorizing the construction of a traffic-bridge to take the place of the ferry, the cost to be covered by endowment from the Government to the extent of one-half the total outlay, and the remaining half to be advanced by way of loan to the local Authorities, repayable in 40 years by annual instalments on account of principal and interest, calculated on the basis of 5 per cent. of the principal amount. Definite action towards the construction of the bridge was not, however, taken until the lapse of 8 years after the passing of the authorizing Act. Designs were prepared by Mr. A. B. Brady, M. Inst. C.E., Chief Engineer for Bridges, and tenders were invited for the construction of a steel girder-bridge on cylinder foundations, 1,352 feet 4 inches in length between abutments. The tender of Messrs. John McCormick and Son was accepted, work was commenced on 14th June, 1898, and the bridge was completed and opened for traffic on 24th August, 1900.

In common with all Queensland rivers, the Burnett River is subject to heavy floods. The flood of 1890 (the highest on record) rose to a height of 27 feet 4 inches above high-water of ordinary spring-tides, and the level of the underside of the girders in the new bridge was fixed at 4 feet above this level.

Foundations.—On the north side, at Bundaberg, the flood-bank recedes to a distance of 650 feet from the ordinary bank of the river, the intervening flats of sand and other flood-deposits giving evidence that the bed of the river was at one time farther north than it is at present. This assumption has been confirmed to some extent by the river in recent floods having shown a tendency to scour through these flats, and the foundations throughout the structure have been carried to such a depth as would avoid any

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risk of disturbance in the event of such a contingency occurring in the future. The cylinders (Figs. 2, Plate 6), forming the two columns of each pier, were sunk by dredging with a single-chain "grab" until the material became too hard and compact for further progress by this means, when the excavation was completed by divers supplied with air under pressure by a steam compressor delivering into a receiver on the bank of the river. The depths at which dredging was suspended in the several piers are shown by a dotted line in the elevation (Fig. 1, Plate 6), which indicates the stable bed of the river, not likely to be disturbed by any future flood-scour. Borings taken prior to the preparation of the designs appeared to indicate that rock bearings for the foundations could be secured for all the piers throughout the structure, but these expectations were not realized, as in sinking Piers 1, 2 and 4, and the upstream column of Pier 5, no rock was found. The strata forming the banks and bed of the river are wholly sedimentary, and in places where rock existed it was of a flinty sandstone only a few feet in thickness, and overlying a bed of great depth of hard pipe-clay. The superimposed weight on the foundations of each pier is approximately 1,000 tons, or 460 tons and 540 tons respectively on the upstream and downstream columns. In this estimate the skin-friction on the exterior of the columns is not considered, but a live-load of 100 lbs. per square foot is allowed, to provide for dense crowds on any part of the bridge, whilst no extra allowance is made for any increased pressure which may be transmitted to the downstream columns by the action of flood-stresses. The cylinders are 7 feet in diameter, or 38·48 square feet in cross-sectional area, giving a maximum pressure of 14 tons per square foot on the foundations. Under the conditions of the contract, each column was required to sustain, without sinking, a load of 100 tons in addition to its own weight, before being filled with concrete. The columns of Piers 3, 5, 6 and 7 (Fig. 1, Plate 6), founded on rock, were successfully tested under these conditions. The columns of Pier 4 and one of the columns of Pier 5 were founded on a hard pipe-clay, perfectly dry and impervious to water. These columns were also loaded, and satisfactorily sustained the test-weight upon the bulb of the cutting-edge of the bottom cylinders, this being equivalent to a pressure of about 30 tons per square foot upon the bearing surface. The pipe-clay inside the cylinder, however, being free to rise under the wedging action of the bulb, it was considered at the time that the column, if tested by the imposition of a sufficient weight after it had been filled with concrete, would show a much increased

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bearing-power per unit area of surface, and that the margin was sufficient for practical purposes. At Pier 2 the bed of the river consisted of 14 feet thickness of loose sand and gravel, with a layer of clay overlying the rock. As this material was liable to be scoured away in heavy floods, it was provided in the original designs that in this pier, and also in Pier 1, the columns should be sunk at least 8 feet and 12 feet respectively into the solid rock, as a precaution against any sliding or overturning action resulting from the flood-stresses upon the piers. After the removal of the loose material at Pier 2 by means of a "grab," excavation in the clay and rock was effected by the plenum process, the column being fitted with an air-lock and supplied with air under pressure from the steam compressor and receiver upon the bank of the river. The rock in this pier, however, proved to be only about 4 feet in thickness, overlying a bed of pure hard pipe-clay, of great depth and perfectly dry, into which Column C was sunk 9 feet, with 58 tons of dead-weight, in addition to the weight of the column itself, supported on the bulb of the cutting-edge, Figs. 2, Plate 6. It was then loaded up to 95 tons, or practically the test-weight, which caused the column to sink gradually an additional 18 inches, the surface of the clay inside the column then reaching the top flange of the bottom length of cylinder, and assisting somewhat in supporting the weight, although not to a great extent, as the clay did not squeeze freely from under the flange. As the bottom was dry and solid it was not considered necessary to remove the clay down to the cutting-edge; it was, however, rammed with spawls, with heavy two-man rammers, and the concrete seal was laid immediately. To avoid any risk of the water finding its way down the outside of the cylinders, where the ½-inch projection on the exterior of the cutting-edge had probably left a cavity in travelling through the stiff pipe-clay, it was considered advisable not to delay this work. When Column D (Figs. 2, Plate 6) passed through the rock, supporting 55 tons of rails in addition to the weight of the lock (8 tons) and the weight of the column itself, it sank 2 feet 3 inches into the clay; the weight was then increased to 95 tons and the column dropped gradually through an additional 4 feet 8½ inches; at this level it remained stationary when the clay was completely relieved from under the top flange of the cutting-length.

Neglecting skin-friction, the weights imposed on the area of the bulb of the cutting-edge were equivalent to a pressure of 34 tons per square foot of surface; it therefore might reasonably have been assumed that a factor of safety of at least 3 was

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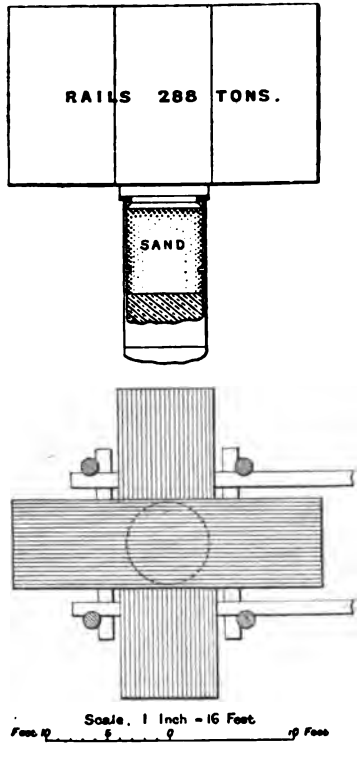
ensured. The skin-friction, in the case of this pier, was not considered an important element in the estimate, on account of the character and small depth of the sinkage. The comparative lowness of the factor, however, called for further investigation, and it was decided to apply additional tests to these columns in the form of dead-weight loading, after the concrete filling had been completed. The Author was fortunate in securing the loan from the Railway Department of a sufficient quantity of rails, which had been lifted from the Mount Perry line for replacement with heavier rails, and which happened to be in process of delivery at Bundaberg for shipment to the north by steamer. These served the purpose admirably. As the concrete in the cylinders could not be carried higher than about 8 feet from the top of the 7-foot cylinders, to allow for fixing the cast-iron bracing, the remaining space was filled with sand, solidly rammed (*Figs. 5*), and as the whole weight had to be carried upon a circle 6 feet in diameter, the problem of safely imposing the test-weight required some consideration in order to avoid accident. The surface of the sand-filling having been carefully levelled, a platform of hardwood was prepared and laid upon it, carrying a solid tier of 12-inch hardwood baulks, upon which the rails, 26 feet in length, were stacked, *Fig. 6*. The rails were interlocked so as to form as nearly as possible a solid mass of iron. Great care had to be exercised in carrying up the stack, each rail being centred so as to ensure the whole mass being perfectly vertical and central with the column. The top cylinders of each column were carefully examined all over with magnifying-glasses, in order to discover any cracks in the castings which might cause a failure

Figs. 5.



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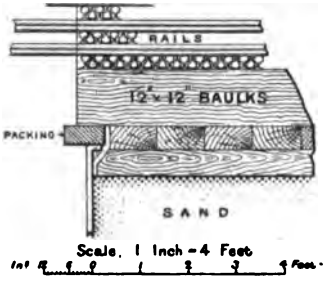
under internal pressure from the compression of the sand. After being loaded with 170 tons, the sand-filling was compressed $2\frac{1}{2}$ inches, and pine packing was then carefully fitted between the timber baulks and the top of each column, the remainder of the weight being taken upon the cylinders, *Fig. 6.* During these tests the Author detected a slight sinkage of Column C when only 116 tons had been packed on it, the sinkage increasing to $\frac{3}{8}$ inch with 153 tons, $1\frac{5}{16}$ inch with 193 tons, and $3\frac{3}{4}$ inches with 253 tons. Under a similar test Column D had sunk $\frac{1}{8}$ inch with 130 tons, increasing to $2\frac{3}{4}$ inches with 253 tons, the sinkage continuing, with 288 tons, at the rate of $\frac{1}{16}$ inch in 24 hours, up to $6\frac{3}{16}$ inches, when the necessity for returning the rails immediately for shipment prevented further continuance of the test. The tests having conclusively proved the insufficiency of the surface provided to carry the weight on the piers, where these were founded on the pipe-clay, it was decided to increase this surface at Pier 2 by sinking an additional caisson, 13 feet in diameter, around each column, from the bed of the river to the surface of the rock, and to fill it with concrete, thus increasing the bearing-surface from 38·48 square feet to 132·7 square feet, and reducing the pressure upon the foundations to about 4 tons per square foot. Caisson-plates of cast iron, $\frac{7}{8}$ inch in thickness, of ordinary tank-construction, were procured locally, and a timber framing was prepared for carrying the weight for sinking, above the surface of the water, Figs. 2, Plate 6. Guides of pine blocks were provided to keep the caisson concentric with the column, and about 15 tons of rails were sufficient for weight. The concrete was deposited in self-releasing skips. The top of the concrete was then carefully worked by divers to a level with the top of the caisson, to a template working against the face of the column, and was plastered with a chunam of tar and cement, upon which a heavy cast-iron frill (Figs. 2, Plate 6) was bedded and bolted round the column with $3\frac{1}{4}$-inch tension-bolts, set up by divers, with large sledge-hammers upon a heavy box-spanner provided for the purpose. Eight holes were then drilled by the divers, through the frill and the cylinders of the column, and steel pins $2\frac{1}{4}$ inches in diameter were inserted; the

Fig. 6.



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whole was then covered up with cement-concrete and finished off as shown in Figs. 2, Plate 6. The reinforcement-works at Pier 2 were executed after the bracing of the piers, and the girders and trough-decking, had been erected.

Column A of Pier 1 entered the pipe-clay after passing through a band of hard flinty sandstone about 3 feet in thickness. As the clay proved perfectly water-tight the air-lock was removed, and the excavation was carried on in the open, until the column, having been sunk 16 feet into the clay, hung with 40 tons additional weight, or a total of 70 tons, the bottom being undercut 15 inches below the cutting-edge, thus demonstrating the practicability of enlarging the supporting-area of the pier by undercutting in the clay to the extent required. All superfluous weight was therefore removed, the column was wedged up in the leaders, and a cavity 10 feet in diameter was carefully excavated to template in the clay, under the cutting-edge of the cylinder, and filled in with 3, 1½, and 1 concrete to above the level of the bulb, lengths of rails being built in to the concrete to strengthen the overhang, Figs. 7, Plate 6. Column B was treated similarly, except that the base was enlarged to 11 feet in diameter (Figs. 7, Plate 6) corresponding to a pressure on the foundations of 5·7 tons per square foot. The remaining columns founded in the pipe-clay, namely, G and H of Pier 4, and I of Pier 5, were strengthened by driving around each column eight hardwood piles, 50 feet in length, of grey ironbark 21 inches in diameter, the piles being driven until the movement produced by three blows of a 30-cwt. monkey falling 10 feet did not exceed 1⅛ inch. The heads of the piles were then sawn off level, and cast-iron frills similar in all respects to those provided for Pier 2 were bedded on them and secured to the columns, the whole being then enclosed in concrete, Figs. 8, Plate 6.

Abutments.—The abutments are wholly of concrete gauged 5, 2 and 1, and are carried on grey ironbark piles, spaced 4 feet apart, in rows 3 feet 8 inches apart, centre to centre, Figs. 3, Plate 6. The piles are 18 inches in diameter at the head, and are capped with hardwood, 12 inches by 12 inches, the heads being covered in concrete to a depth of 3 feet. The drainage was kept down in the south abutment by a powerful Pulsometer pump drawing from a sump below the level of the bottom of the excavation, which was afterwards filled up solid with concrete.

Staging.—The staging for sinking the cylinders was of the ordinary arrangement, each column being retained in its correct position by four hardwood guides, provided with wedges at the

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back, by which the friction could be regulated at will. Seals of concrete were laid in all the columns sunk by divers, and the water was baled out by means of a canvas baler 2 feet 4 inches in diameter by 4 feet in depth, worked by a steam-winch and lifting 3,000 gallons to 3,500 gallons per hour.

Superstructure.—The superstructure is formed of steel girders of the ordinary hog-back lattice construction, carrying Lindsay trough-plates on the bottom flanges of the booms. The troughs are brought up level with concrete, and on this the roadway is formed, of tarred metal asphalt with concrete water-tables on each side. The girders were manufactured in Brisbane at the works of the contractor, and the booms were delivered at Bundaberg in sections of 24 feet to 25 feet in length, the struts and ties being forwarded loose. They were erected on false-works, consisting of a nest of eight hardwood piles, 15 inches in diameter at the head, driven in the centre of each span, strongly braced and supporting Oregon pine trussed beams from false-works clamped to the piers. The tension-member of each truss was formed of six wire-ropes, 3 inches in circumference, set up with tackle and spliced over cast-iron ferrules at the ends of the beams. These trusses were framed on the contractor's wharf and were lifted into position by a steam-derrick on a punt. The girders were erected on blocks to a sufficient height for riveting under the booms, and, when completed, the span, including the troughs, was lowered on to the bed-plates by means of two 100-ton hydraulic jacks supported on the false-works secured to the piers. The whole of the material for the river-spans, except the centre length of the top booms, was lifted directly into position by the steam-derrick.

A small flood occurred in the Burnett River in January, 1899, bringing down a great quantity of megass, brushwood, and other debris, which accumulated against the staging and piers, and formed a mattress extending over two spans. No damage, however, resulted, as the girders were sufficiently advanced to be self-supporting, and the staging withstood the immense stress imposed, until relieved.

The total cost of the bridge and approaches was £64,234, including the purchase of land for the north approach, and engineering and supervision. The bridge was completed and opened for traffic by the Right Honourable Baron Lamington, G.C.M.G., Governor of Queensland, on 24th August, 1900.

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The Kennedy Bridge.

The eastern boundary of Bundaberg is formed by an arm of the Burnett River, named Salt Water Creek, and communication with the numerous sugar-plantations throughout the Woongarra scrub, between the town and the sea-coast, some 9 miles distant, was established in 1875, by the erection of a wooden bridge. The traffic, which is considerable, consists largely of coal and timber for fuel for the mills, sugar for shipment, machinery, and other very heavy loading, and, the timber bridge having been condemned as unsafe, steps were taken by the joint Board appointed by the local Authorities interested, to construct a new bridge of a permanent character and adequate to the traffic. Designs were prepared by Mr. A. B. Brady, M. Inst. C.E., a single span in all respects similar to that of the Burnett Bridge, carried upon concrete abutments, being adopted, Figs. 10, Plate 6. Funds were provided under the local Works Loans Act of 1880, whereby the Government contributed one-third of the total cost, the remaining two-thirds being advanced to the local Authorities interested, namely, the Bundaberg Municipal Council and the Woongarra Divisional Board, by way of a loan, repayable in 40 years by annual instalments, calculated on a basis of 5 per cent. on the capital amount.

The total cost of the bridge and approaches was £6,999 5*s*. and it was completed and opened for traffic by the Hon. John Murray, M.L.A., Minister for Public Works, on 25th November, 1899. The works were carried out under the direction of Mr. A. B. Brady, M. Inst. C.E., Under-Secretary for Public Works, Government Architect, and Engineer for Bridges, Queensland, with the Author as Superintending Engineer for the manufacture of the material and the erection of both bridges, his assistants being Messrs. W. J. Ewart, and J. H. Daniells. The Contractors, both for manufacture and erection, were Messrs. John McCormick and Son, to whom much credit is due for the satisfactory manner in which they carried out the contract.

The Paper is accompanied by four drawings, from which Plate 6 has been prepared, and by nine photographs and the following Appendix.

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APPENDIX.

Quantities, and Prices paid for the Principal Items of Work in the Bridges and Approaches.

Burnett Bridge.

Description of Work.	Quantity.	Rate. £ @ s. d.
Excavation.		
Excavation in foundations for concrete abutments and retaining-walls "soft" .	1295·25 cubic yards	0 10 0
Excavation in foundations for concrete abutments and retaining-walls "rock" .	206·0 „	0 15 0
Excavation in sinking cast-iron cylinders to level of hard bed-rock	898·56 „	1 0 0
Excavation in sinking cast-iron cylinders to any required depth in rock	120·67 „	10 0 0
Excavation for fixing spandrils, Piers 7, 6 and 5	46·2 „	0 10 0
Pile Foundations.		
Ironbark piles in foundations, 17 inches in diameter at head and 12 inches in diameter at toe, not exceeding 60 feet in length, driven	2323·53 lineal feet	0 6 0
South abutment Ditto	934·78 „	0 4 6
Sawn or squared ironbark in capsills and planking	409·0 cubic feet	0 5 0
Ditto south abutment . . .	154·0 „	0 3 9
Wrought iron in pile-shoes, drift-bolts and spikes	3042·8 lbs.	0 0 3
Cement-Concrete Work.		
Cement-concrete in foundations, abutments, wing- and retaining-walls, parapets, pilasters, newels, etc. (5, 2 and 1)	1889·5 cubic yards	1 17 0
Cement-concrete filling in cylinders and cornices (6, 3 and 1)	1447·0 „	1 15 0
Cement-concrete on trough-decking (6, 3 and 1)	617·34 „	1 10 0
Cement-concrete in bed-blocks, water-tables and curbs (3, 1½ and 1)	155·3 „	2 5 0
Cement- and coke-concrete in footway (4, 2 and 1)	166·3 „	2 0 0
Dry Rubble Backing.		
Dry rubble backing to abutments, etc. . .	150·7 „	0 5 0

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BURNETT BRIDGE—*continued.*

Description of Work.	Quantity.	Rate. £	@ s.	d.
Cast Iron (including erection).				
Cast iron in cylinders	525·9 tons	17	0	0
Cast iron in moulded bases, caps, cornices, and neck enrichments of cylinders, and bracing spandrils to piers	86·7 ,,	19	0	0
Cast iron in bed-plates, bearings, saddles, gulleys and scuppers, newels and brackets for gas-tube railings	23·5 ,,	25	0	0
Cast Steel (including erection).				
Cast steel in bed-plates, expansion-rollers, and rocking-pins	9·7 ,,	50	0	0
Steelwork (including erection).				
Steel in main girders and cross-girders, overhead bracings, footway cantilevers, etc.	847·5 ,,	24	0	0
Steel trough-plates (Lindsay) in bridge-decking	433·3 ,,	17	0	0
Steel corrugated flooring to footway	58·8 ,,	17	0	0
Wrought Ironwork (including erection).				
Wrought iron in bracing to piers	25·8 ,,	35	0	0
Wrought iron in lattice parapet to footway, anchor-plates to abutment-cantilevers and side-plates, angle- and bulb-bars on footway	59·0 ,,	24	0	0
Wrought-iron turned bolts, nuts, screws, washers, pins and lewis-bolts in piers and superstructure	17,278 lbs.	0	0	10
Wrought-iron gas-tube railings on girders	15·0 tons	35	0	0
Hardwood.				
Wrought and moulded capping to footway-parapet	1420·0 lineal feet	0	1	6
Tar-Metal and Footway-paving.				
Tarred metalling and screenings to roadway of bridge	762·0 cubic yards	0	17	6
Tar paving to footway 1¾ inches thick	1075·0 square yards	0	2	6
Approaches.				
Earthwork in embankments in excess of material from excavations	3,993 cubic yards	0	1	9
Stone-pitching on slopes of embankments	162·0 ,, ,,	1	10	0
Metalling and blinding on roadways and footpaths	492·0 ,, ,,	0	10	0
Sawn or squared ironbark in curbs, gravel-boards, etc.	659·0 cubic feet	0	4	0
Sawn or squared ironbark in fencing	276·3 ,, ,,	0	5	0
Wrought ironbark in fencing	271·3 ,, ,,	0	6	0
Wrought ironwork in bolts, nuts, washers, straps, etc.	986·5 lbs.	0	0	3

Portland cement cost 13*s.* 6*d.* to 14*s.* per cask gauging 4½ cubic feet loose, delivered at the works, and the rates paid for labour were 6*s.* to 7*s.* per day for labourers and 8*s.* to 10*s.* per day of 8 hours for mechanics.

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KENNEDY BRIDGE.

Description of Work.	Quantity.	Rate. £ @ s. d.
Excavation.		
Excavation in foundations for concrete abutments	553·0 cubic yards	0 5 0
Pile Foundations.		
Ironbark piles in foundations 17 inches in diameter at head and 12 inches in diameter at toe, not exceeding 50 feet in length—driven	2683·5 lineal feet	0 5 0
Sawn or squared ironbark in capsills	320·0 cubic „	0 5 0
Wrought iron in pile-shoes, drift-bolts, and spikes	2500·0 lbs.	0 0 3
Lewis-bolts	63·0 „	0 0 4
Cement-Concrete Work.		
Cement-concrete in foundations, abutments, wing-walls, pilasters, etc. (5, 2 and 1)	553·7 cubic yards	1 17 0
Cement-concrete in trough-decking (6, 3 and 1)	77·3 „ „	1 10 0
Cement-concrete in bed-blocks, water-tables, and curbs (3, 1½ and 1)	37·8 „ „	2 5 0
Cement- and coke-concrete in footways (4, 2 and 1)	15·5 „ „	2 0 0
Cast Iron (including erection).		
Cast iron in bed-plates, bearings, saddles, gulleys, scuppers, newels, and brackets for gas-tube railings	5·0 tons	25 0 0
Cast Steel (including erection).		
Cast steel in bed-plates, expansion-rollers, and frames and rocking-pins	23·1 cwts.	2 10 0
Steel Work (including erection).		
Steel in main girders, end cross-girders, overhead bracings, footway-cantilevers, etc.	106·1 tons	24 0 0
Steel trough-plates (Lindsay) in bridge-decking and corrugated plate flooring for footway	61·4 „	17 0 0
Wrought Ironwork (including erection).		
Wrought iron in lattice-parapet to footway and side-plates, angles, and bulb-irons to footway, expansion-plates, etc.	7·9 „	24 0 0
Wrought-iron turned bolts, etc.	822·0 lbs.	0 0 10
Wrought-iron gas-tube railings on girders	2·0 tons	35 0 0
Hardwood.		
Wrought and moulded hardwood capping to footway parapet	185·0 lineal feet	0 1 6

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KENNEDY BRIDGE—*continued.*

Description of Work.	Quantity.	Rate. £	@ s.	d.
Tar-Metal and Footway-paving.				
Tarred metalling and screenings to roadway of bridge	86·0 cubic yards	0	17	6
Tar paving to footway 1¾ inch thick	136·0 square „	0	2	6
Approaches.				
Earthwork in embankments in excess of material from excavations	760·0 cubic „	0	1	9
Stone-pitching 12 inches in thickness on slopes of embankments	72·6 „ „	0	15	0
Stone-pitching 7 inches in depth on roadways	85·2 „ „	1	5	0
Metalling and blinding on roadways	240·0 „ „	0	7	0
Wrought ironbark in fencing	117·0 cubic feet	0	6	0
Sawn or squared ironbark in fencing, curbs, gravel-boards, etc.	346·6 „ „	0	4	6
Wrought iron in bolts, straps, etc.	347 lbs.	0	0	3

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(*Paper No. 3385.*)

"Permissible Wheel-Load per Foot of Wheel Diameter, and per Inch of Breadth of Rail-Head."

By FRANCIS JOSEPH EDWARD SPRING, C.I.E., M. Inst. C.E.

IN the following notes an attempt is made to formulate some measure of co-ordination between wheel-load per inch diameter of wheel, and the factors on which, regarded from the standpoint of wear and tear, it ought, in the Author's opinion, to be dependent.

The rule now in force for Indian railways fixes the axle-load per foot of wheel-diameter separately for the two gauges, viz., 3·75 tons for the 5-foot 6-inch gauge and 3·00 tons for the metre-gauge; being equivalent to 350 lbs. and 280 lbs. respectively, per wheel, per inch of wheel-diameter. The only reason the Author can assign for this differentiation between the gauges is that it has all along been recognized that wear and tear depend not merely on the load, but also on the area of the mutually abrading surfaces, of which the breadth of the rail-head is an element. The permissible axle-load of 3·75 tons per foot of wheel-diameter is liable to run on rails having heads varying in breadth between 1·75 inch and 2·33 inches, while the corresponding 3·00-ton load is liable to run on rails varying between 1·25 inch and 1·66 inch in breadth of head.

The Author proposes to apply the term "Index Number" to "wheel-load in pounds per inch of wheel-diameter, per inch width of moderately worn rail-head." In India the Index Number, which the Author considers to be the proper measure for abrasion, varies between 224 for the narrowest metre-gauge rail and 107 for the widest broad-gauge rail in use on the railways. If the 75-lb. rail, with a head 2 inches in breadth when worn down $\frac{1}{10}$ inch at the centre, be taken as the standard for rails on which freight-cars having wheel-loads of 350 lbs. per inch diameter run; and if the 50-lb. rail, with a head 1·66 inch in breadth when worn down $\frac{1}{10}$ inch at the centre, be taken as the standard for wheel-loads of 280 lbs. per inch diameter, Indian Index Numbers 150 for

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standard-gauge and 155 for metre-gauge are obtained. The next point for consideration is whether these are habitually exceeded or not, on large railway systems elsewhere, where this particular question of railroad economics appears to receive the attention that it deserves.

Decision as to a maximum wheel-load for wagon-stock is influenced by the consideration that, when a certain wheel-load per inch of wheel-diameter is reached, the economy that results from increased loading, or the convenience that results from a smaller wheel, is counterbalanced by the wear of the surfaces of the rail and wheel, as well as by the wholesale scrapping of rails not fit to be left in the road. One-quarter inch of wear off the top of an Indian 75-lb. rail means a loss of weight of about 6 lbs. per yard, and doubtless the equivalent of another 6 lbs. per yard of rail off the wagon-wheels which have been responsible for the wear. This amounts to 943 tons (representing 100,000 to 150,000 rupees), for 100 miles of railway, for loss of steel alone. The railway economist must compare this loss, and the approaching scrapping of the rails, with the gain from heavier wheel-loads; for rails calculated for certain loads cannot, considered as girders, safely go on carrying those loads when their weight is reduced by more than 8 or 10 per cent.

The question, then, for the economist is: How many years is it permissible to allow before scrapping rails, such scrapping being the price paid for the saving in working expenses which results from increased wheel-loads? Needless to say, with the available data, the problem is not soluble on theoretical considerations. All that can be done is to judge in a general way whether existing wheel-loads are so light as probably to give too long a life to the rails. Guidance in regard to this can be obtained from experience in England, America, and elsewhere. If well-managed roads are found where higher wheel-loads are tolerated than in India, it may safely be concluded that the managers of these roads are satisfied that it pays, for the sake of higher loads, to scrap their rails somewhat earlier. It is conceivable that for the sake of better loads it might pay to scrap rails wholesale in 10 years instead of in 20 years; or after so many million tons had passed over them, instead of double that number; or after so many heavy wheel-loads had rolled past, instead of double the number of light wheel-loads; or after some agreed percentage of weight from wear and tear, and corrosion, had been lost. The Author does not propose, however, to investigate the whole question, the available data being inadequate. Some valuable data are contained in Mr.

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P. H. Dudley's Report of the Sixth Session of the International Railway Congress, 1900, but even these are inadequate for the satisfactory solution of so complicated a problem. The Author proposes, therefore, simply to endeavour to ascertain how the load may vary with the wheel-diameter and with the breadth of the rail-head.

A newly-turned wheel can be in contact with a newly-rolled rail only over a very restricted area, because the wheel and the rail-head are both parts of cylinders, and the theoretical contact of two cylinders is a point. After some time, when the rail gets worn down, the surface of the rail-head becomes a plane, and the wheel still remains a cylinder (or a truncated cone), so that the contact between the two takes place no longer at a point, but on a line. Both the wheel and the rail-head being elastic, there is mutual yielding at the point or along the line of contact, so that the point becomes a more or less circular area, and the line a more or less irregular parallelogram. When the load is increased, the area extends until the load is balanced by the total resistance of the compressed elastic metal over the whole contact-surface. In the long run, the amount of wear and tear of the tire and rail-head will depend chiefly on the intensity of stress which is permitted to occur in the worst-stressed fibres of the contact-area. A traffic of 100 trains (say, 4,000 wheels) per day gives, say, 15 million compressions to the rail-top in 10 years. If these 15 million compressions are of such intensity that the stress in the worst-treated fibre exceeds the elastic limit, there necessarily will be flow or disruption of the rail-head; and even if the stress be comparatively moderate, there necessarily must be wear and tear of the mutually-abrading surfaces of the wheel and rail. For similar wheel-loads and similar rails, intensity of stress is a function of wheel-diameter since the length (along the rail) of the small compression-area is clearly proportional to the wheel-diameter.

A rail with a small radius of head, say, 5 inches, such as the Indian 62-lb. or 80-lb. rail, or 5½ inches, like the 41¼-lb. rail, sustains at first great wear and tear, because the wheel-loads produce an extremely large intensity of stress on the small contact-surface. This in time cures itself, and after a rapid initial wearing down, and probably also flow, at the centre of the rail-head, the radius may increase to any extent, even to infinity, which gives a flat head. The better-designed rails have larger head-radii; thus the 50-lb. metre-gauge rail has a radius of 15 inches, and the 100-lb. 5-foot 6-inch gauge rail has a radius of 12 inches. Even these wear down in time to more or less a straight line on the rail-section. The object is

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that, after the first few years of roughing down, the ratio of wheel-load to contact-area shall be such as to allow of the rail being retained in use for that period which has been decided to be its economical life, as conditioned by the traffic economy which follows the use of heavier wheel-loads. These considerations lead the Author to put forward the following as a fair ordinary type of design of rail-head. He does not specify radius of head, considering that this must to some extent depend on the technics of rolling-mills. What is aimed at is a rough rule giving breadth of wheel-tread after moderate average wear and tear :—

"When $\frac{1}{10}$ inch shall have been worn off the summit of the rail-head, the breadth of the worn top shall be, in inches :—

$1 + 1\frac{1}{3} \times$ weight of rail in hundred pounds per yard; or,

1 + four times the weight of the rail in hundred pounds per foot."

This accords with good existing Indian practice for rails weighing between 50 lbs. and 100 lbs. per yard.

Considerable light is thrown on this important branch of railway economics by two Papers read before the American Society of Civil Engineers, and the discussions thereon, namely :—(1) "Destruction of rails by excessive weights," by Mr. Joseph T. Dodge,[1] and (2) "Cylindrical wheels and flat-topped rails for railways," by Mr. D. J. Whittemore.[2] From these very instructive Papers the following is extracted as being likely to aid in arriving at a suitable expression for axle-load per foot of diameter of wheel to suit various rails.

Mr. Dodge, in discussing the observed bulging out, or flow, of rail-heads, and ascribing it to the excessive intensity of load per unit of contact-area when rails having a small top-radius are used, observed that bearing-areas vary with the radii of the wheels and with the width of the rail-heads. He mentions an eight-wheel freight-car weighing 25,000 lbs., and carrying 41,000 lbs., as being as destructive of rails as a consolidation-engine carrying 96,000 lbs. on its eight driving-wheels, of 4 feet diameter. Presumably, the car-wheel was the American standard 33-inch wheel, and in this case the axle-load would be only 7·36 English tons, or 2·68 tons per foot diameter. The axle-load of the engine would be 10·71 tons, or 2·68 tons per foot diameter. These are certainly not high. In the discussion on Mr. Dodge's Paper Mr. W. W. Rich mentioned

[1] Transactions American Society of Civil Engineers, vol. xx. p. 121.

[2] *Ibid*, vol. xxi. p. 133.

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a car weighing 27,000 lbs., and carrying 50,000 lbs. on eight 33-inch wheels. This would give an axle-load of 8·14 tons, or 3·12 tons per foot diameter. These two are not even as high as the highest permissible Indian loads, which are 3·75 tons and 3·00 tons, for 5-foot 6-inch gauge and metre-gauge respectively, *i.e.*, for use on rails 1·75 inch to 2·25 inches and 1·25 inch to 1·50 inch in breadth respectively. The American figures are, however, 13 years old. Mr. Rich's reference to the latter car was in connection with observed contact-areas of $\frac{1}{10}$ square inch to $\frac{1}{11}$ square inch between wheel and rail; this means a stress of 100,000 lbs. per square inch, which would at once account for flow. He mentions a switch-engine with 16,000 lbs. on a 52-inch wheel, which means an axle-load of 14·28 tons, or 3·31 tons per foot diameter, as "leaving its record about the yard in some good-sized splinters rolled from the rail-heads." In the same discussion Mr. Thomas Rodd spoke of twelve-wheel cars weighing 120,000 lbs. gross. This would give an axle-load of about 9 tons, or 3·25 tons per foot diameter of wheel. It is evident that American practice of 13 years ago was behind present Indian practice in the matter of relationship of load to wheel-diameter. It appeared incidentally in the discussion on Mr. Dodge's Paper, that it was not at that time the practice in America to cant rails with a view to bring their top surface into approximate coincidence with coned car-wheel treads. This has invariably been done in India for the last 30 or 40 years.

With regard to Mr. D. J. Whittemore's Paper, and the extremely valuable discussion thereon, the Paper and discussion occupy 170 pages, contain a large number of plates, and are teeming with facts. The admitted fact that many millions of dollars' worth of rails and car-wheels go annually to the scrap-heap in the United States, is a practical commercial measure of the importance of the subject under consideration, which is: How are car-wheels to be loaded so that the cost of this scrap-heap shall be more than balanced by the reduction of cost of haulage caused by the general use of heavier wheel-loads? In India, uses are found for old rails, in fencing, telegraph-posts, buildings, feeder-railways, etc., and they have thus a good market value; but there is heavy loss on them, nevertheless, as well as on wheel-tires broken down, worn, returned, and scrapped. These losses, whatever they amount to, are affected by wheel-loads per foot of wheel-diameter and per inch of rail-tread, and, if the working is to be economical, must be more than covered by savings in cost of haulage of paying freight.

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Mr. Whittemore has investigated the theoretical considerations which govern the destructive effects of wheels of various radii resting on rails with various radii of top table, up to flatness, and he has shown that a wheel which rests on 1 inch breadth of flat rail-top is fully four times less destructive than when it rests on a rail-top of even 12 inches radius, and when the flat rail-top is 2 inches in width the superiority is twice as great. This becomes even more accentuated when the radius of rail-top becomes smaller, as in the ridiculous 5-inch radius of the Indian 41¼-lb., 62-lb. and 80-lb. rails. Needless to say, the fault of too small a rail-top radius tends to correct itself before many million tons have passed over the rail, and within the first few years of heavy traffic the 5-inch radius becomes in turn, 8 inches, 12 inches, 15 inches, and infinity, so that a well-worn rail has a good flat top, and wear proceeds more slowly as years go on. There is less flow as well as less crushing. It may quite conceivably be true that when rolls are so shaped as to give a small top-radius they prepare the steel better for resisting wear than when they are shaped so as to give a large top-radius. That this is the case may be gathered from Mr. C. P. Sandberg's remarks on Mr. Whittemore's Paper.[1] But the Author doubts whether the gain—if there is gain—due to this cause is not more than compensated for by the greater destructive effect of the smaller contact-area between wheel and rail that must ensue with small radii of rail-head. Indeed, Mr. Sandberg, although insisting on the better rolling with a 5-inch radius, was willing 13 years ago to accept the larger radii now prevalent. All this leads up to the Author's contention that, however ill-designed Indian rails may be at first, in smallness of top radius, that fault corrects itself with wear and tear, so that there is full justification for considering fair breadth of well-worn top to be a factor in the problem of how to proportion loads to wheel-diameters.

From that splendid summary of American practice in respect of wheels and rails, already referred to, namely, Mr. P. H. Dudley's Report, it appears that the axle-loads commonly employed in the United States are:—

For freight-cars of	60,000	lbs. capacity,	23,000	lbs.	per axle	for 33-inch wheels.
,,	,,	80,000	,,	27,800	,, ,,	
,,	,,	100,000	,,	35,000	,, ,,	

So far as the Author has been able to ascertain, the rails on which

[1] *Loc. cit.*, p. 167.

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these highly concentrated loads are run vary between 80 lbs. and 100 lbs. per yard, with heads which, when a little worn, vary in breadth between 2·08 inches and 2·60 inches. Their Index Numbers can therefore be calculated, and are given in the following Table:—

Load per Axle.	Load per Wheel.	Load per Inch of Wheel Diameter.	Breadth of Worn Rail-Head.	Index Number.
Lbs.	Lbs.	Lbs.	Inches.	
23,000	11,500	348	2·08	167
27,800	13,900	421	2·34	180
35,000	17,500	530	2·60	204

If, however, the heaviest load runs on the 80-lb. rail the Index Number will be 255. The Author thinks it probable that 200 may be taken as a fair Index Number for American approved practice, on roads where due care is devoted to proper co-ordination between the operating economy due to heavier loads and the wear and tear involved in the use of such loads. He therefore inclines to the opinion that an Index Number of 200 might well be adopted for India. The Index Number in India at present is not far from 155.

The Author has recently been called upon to advise on this important question of practical railway economics, owing to the fact that, quite recently, the Consulting Engineer to an Indian Railway Company prepared a design for a goods-wagon of 70,560 lbs. gross weight on eight 33-inch wheels, which he was prepared to use at first for gross weights of 52,720 lbs. These give axle-loads of 17,640 lbs. and 13,180 lbs., or 534 lbs. and 400 lbs. per inch of wheel-diameter. The loads and wheel-diameter proposed give an Index Number of 134 for the 85-lb. rail of one section of the line, and of 144 for the 75-lb. rail of another section. It is obvious, therefore, that, so far as wheel-diameter is concerned, the destructive effect of the proposed wheel and wheel-load will be far less than what is accepted as economically permissible in American practice, and less even than what is admitted at present to be permissible in Indian practice. The Author, therefore, was able to advise that he saw no objection to sanctioning the use of 33-inch wheels on 75-lb. to 85-lb. rails, for 31½-ton gross loads on eight wheels.

In conclusion, the recommendations contained in these notes may be summarized as follows:—

(*a*) Rail-heads should be so designed that when $\frac{1}{10}$ inch shall

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have been worn off the summit of the rail-head, the breadth of the worn top shall be, in inches:—

$1 + 1\frac{1}{3} \times$ weight of rail in hundred pounds per yard; or
$1 + 4 \times$ weight of rail in hundred pounds per foot.

(*b*) That, for India, the Index Number, for proportioning wheel-load to diameter of wheel and breadth of rail-head—that is, pounds of load per wheel, per inch of wheel diameter, per inch of rail-head—as per recommendation (*a*)—shall be 200.

If these recommendations be accepted for Indian practice, the permissible axle-load per foot of wheel-diameter may be 4·286 tons for 5-foot 6-inch gauge 75-lb. rails, and 3·571 tons for metre-gauge 50-lb. rails. For roads on which 100-lb. rails may be used, the permissible axle-load per foot of wheel-diameter may be 5 tons. These revised loads would take the place, if accepted, of the present 3·75 tons for the 5-foot 6-inch gauge, and 3·00 tons for the metre-gauge, per foot of wheel-diameter, irrespective of breadth of rail-head.

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(*Paper No. 3403.*)

"Notes on Gold Dredging."

By GILBERT WINSLOW, B.A., Assoc. M. Inst. C.E.

THE method of dredging for gold in "alluvial wash," at present adopted in New Zealand, is the result of some 30 to 40 years' experience. As now carried on, it may be said to be entirely "bucket-dredging," for although suction-pumps have been tried their use has been discarded.

The essential parts of a working dredger are: the pontoons, which form the barge on which all the machinery is placed in position; the ladder-frame, including the buckets by means of which the wash to be treated is raised; the revolving cylindrical screen and tables, or as an alternative, an ordinary sluice-box, in which the wash is treated; the elevator, not always necessary, for returning the treated wash into the river, behind the dredger, in such a position as not to inconvenience dredging operations; and the winches, for altering the position of the dredger by means of ropes fastened to the shore.

The Pontoons.—The pontoons are built of wood or iron. They are always double, with a well about 5 feet in width between them, extending fully half their length, through which the ladder can be lowered.

The Ladder-Frame.—The ladder-frame, built strongly of iron or steel, is so arranged that a chain of buckets can travel continuously round its length. The midship, or upper, end of the ladder-frame, is held at a height of 15 feet to 25 feet above the deck of the pontoons, by a strong framing, but the lower end can be lowered through the well to the depth required, by means of blocks and ropes attached to a bridge-like framing, called the "gantry," on the end of the well. The gantry is so built that the ladder can be hauled entirely out of the water. The buckets discharge their contents, when they have passed their highest point, onto a shoot which directs the wash to the revolving screen, if that is employed, or to the sluice-box.

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The Revolving Screen.—The revolving screen, open at both ends, revolves slowly on its axis, which is out of the horizontal, the end which receives the wash being higher than the other end by 1 foot to 2 feet, depending on the length of the screen. As the screen revolves, material put in at the higher end will in due course be delivered at the lower end. Water plays on the wash in the screen from end to end. The screen is perforated with holes as close together as possible, consistent with strength, and varying in diameter between ¼ inch and 1¼ inch, according to the coarseness of the gold which it is expected to catch. The larger material is delivered from the lower end of the screen into the elevator. All the gold and smaller particles of the wash are washed through the holes, and fall directly on to the tables, which have a width equal to the length of the screen, and a length of about 8 feet or more, if space allows. The tables are covered with plush or felt, having a protection of "expanded metal" laid over it. The fall of the tables may be 1½ inch in 1 foot, and the water frequently flows over the tables with a depth of ½ inch. When once the gold and finer product are on the tables, the separation of the gold is effected by gravitation. The water thoroughly disintegrates the product on the tables, and, at the first opportunity, the particles of high specific gravity, such as gold and heavy black sand, fall through the expanded metal on to the plush, where they are caught. The lighter particles at the same time are carried away by the water. The stream of water must be so adjusted that it is not sufficiently powerful to move gold particles, and yet is too powerful to allow a mass of fine wash to accumulate on the tables, for if this happened the gold could not reach the plush and would be carried away with the tailings from the tables. The tailings are generally allowed to run into the "paddock" behind the dredger. The tables are "cleaned up" at least once a week, and, if much gold is being caught, as often as once a day.

The Elevator.—The elevator consists of a frame, somewhat similar to the ladder-frame, the lower end of which is supported on the stern of the pontoons, the upper end being held by means of ropes suitably attached to the pontoons, at the required inclination to the horizontal—generally about 35° or 40°. A continuous chain of buckets travels up the elevator, and as each bucket reaches the top it discharges its contents over the end.

In general, dredging may be divided into two classes, viz., river dredging, and what is commonly called "dry-land" dredging.

In river dredging the elevator is frequently dispensed with, or is thrown out of gear, since the dredge works up-stream, and any

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stones deposited from the screen over the stern are quickly carried out of the way and do not interfere with the working of the dredger.

In "dry land" dredging, a dredger frequently has to be built to work into a face of auriferous wash or gravel which stands 10 feet to 15 feet above the water-level. In such a case a pond or paddock must be dug, so that the pontoons can be conveniently launched into it. It must be so large that the pontoons can be turned round, with plenty of room to spare. The smallest diameter of the pond should be 40 feet longer than the dredger, for by having extra room much time is saved in "opening out" when commencing work. There is, of course, a limit to the height of the face into which it is possible to work. An elevator cannot deposit gravel masses as closely as nature has done it. A dredger, well managed and having no other special difficulties to cope with, should take down a face of x feet in height, from the surface-level to the bottom which it is proposed to clean up, and deposit the same material, less that which has escaped through the screen-holes, in a vertical height of $\frac{3x}{2}$ feet. Thus if the water-level is 20 feet above the bottom, and a dry face is exposed for a height of 10 feet above water-level, a total face of 30 feet in height is to be dredged, and this when stacked behind should not occupy more than 45 feet vertically. Of this height, 20 feet will be below water-level and 25 feet above it. Tailings-elevators, as at present used, become very cumbersome and expensive if designed to stack more than 25 feet above water-level. Matters can be assisted somewhat by bringing an artificial supply of water into the paddock and keeping the water above its natural level. Under certain circumstances it would be possible to reduce, say, a 20-foot face above, and a 10-foot face below water-level, to a face all below water-level; but this is an extreme case never likely to occur, and such a claim should be proceeded with very cautiously, for, if the natural water-level is so low, it is quite possible that at some previous time much of the ground may have been drained and worked by mining. Moreover, should the water suddenly escape from the pond or paddock, the dredger might become stranded. The dredge attacks a face and deposits it behind, thus continuously moving the pond or paddock onward in any direction it is desired to work. It is always advisable to keep the paddock as wide as possible and to work on a definite system, as this is more economical in every way than working haphazard. If no system be adopted at the start, it may be found at some future time to be

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impossible to work part of the claim without going through old tailings again. In dry-land dredging there is little danger of stoppage due to the dredge being carried away by floods. That, however, is not a very serious item in river dredging, for most dredges can be pulled up by dropping the ladder. Rivers do not lend themselves so readily to prospecting as dry land, and results in river dredging are generally more irregular than those in dry-land dredging, the weekly returns from the river being sometimes very large and sometimes very small.

Difficulties in Dredging.—It may easily be conceived that gold washed down a river may lodge in a crevice in a rock bottom, and may be absolutely irrecoverable by means of a bucket; for this reason a hard bottom constitutes a serious defect in a dredging-claim. Moreover, gold in a face loosened by undermining may fall down and be lost, as far as the dredge is concerned, and thus both the gold on the bottom and that in the higher strata may be lost. Perhaps the most important part of a dredge-master's work is to see that the bottom is cleaned up, and a few inches of it brought to the surface, for gold appears to work its way into a soft bottom. If the bottom is composed of rock no bucket can clear it effectively.

The presence of too much soft clay, or even of any at all, may prove a source of considerable loss. In general, it has been found in New Zealand that in very clayey ground better results are given by a sluice-box than by a revolving screen in the matter of saving gold. It is not difficult to find a reason for this. In a sluice-box, any gold in the wash not mixed with clay has an opportunity, immediately after the disintegration of the wash under the action of a powerful stream of water, to fall to the bottom, between riffles, where the clay lumps cannot reach it. In a screen, however, the gold cannot be expected to go through the first hole it comes to, and that it does not do so in any ground is amply proved by the distribution of the gold across the width of the tables underneath the screen. Until it does find its way through, it will be in constant danger of being picked up by a lump of clay and carried to the elevator and lost.

If a dredging claim happens to be situated in a river into which trees might find their way, and into which much sluicing has been done, there is a strong probability that there will be a certain amount of buried timber. This, if in large quantities, involves a tremendous loss of dredging-time, and may even make a claim undredgeable which without buried timber might be considered ideal dredging-ground. Again, a tree carried away by a flood may occasionally get foul of a dredger or its lines. For this and other

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reasons, if possible, the dredger is frequently drawn into a sheltered position during a flood. A forest on the land to be dredged causes serious inconvenience in many ways. Of course it must be cleared before the dredger can get to work, and as many as possible of the roots should be taken out. These frequently are entangled, and may prevent ground which is undermined from falling in, and generally cause great inconvenience and loss of time. Nevertheless, a forest does not necessarily condemn a claim, for there are claims in New Zealand with thick virgin bush on them, which are now being worked with handsome results. Part of the timber can be burned as firewood, but not all of it lends itself to this use.

In certain rivers, such as the Molyneux, in New Zealand, dredging can be carried on with advantage only during about 7 months in the year; in summer this river is fed by melted snow, and rises and becomes a torrent until cold weather sets in again. A dredge working in a flooded river may have its buckets coming up full and be apparently treating a huge quantity of stuff. Yet this may be only river silt, containing almost no gold, which is being continually washed into the paddock. Sometimes the dredger may even be unable to prevent its paddock from becoming filled up with silt. In some localities, also, severe frost may cause a stoppage of several months every year, or the ground may be undredgeable altogether on account of the severity of the climate, as in parts of Siberia, where the summer thaw only reaches a depth of 6 feet from the surface, the ground below that depth being perpetually frozen. Probably a few weeks for an overhaul once a year are necessary on every dredger, and this, if possible, should be done during a forced stoppage; but, if the stoppage is due to frost, it may be impossible to carry out the overhaul.

If in summer the water-supply runs short, the gold-saving appliances will be seriously affected and considerable loss may result, for the tables require clean water, particularly if the gold is fine. Care should be taken to prevent the dredge touching the bottom in case of shortage of water, as it might easily be ruined through straining, if it grounded.

If the gold to be caught contains large nuggets, and a screen be used, some of the nuggets may be too large to pass through the screen-holes and may become deposited with the tailings. This may be more or less overcome by placing a small sluice-box between the screen and the elevator, so that the material delivered from the screen must pass through the sluice-box before being elevated. A more likely occurrence, however, is that the gold is too fine to be saved easily, and no system of gold-saving applicable in the

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limited space available on a dredge has yet been evolved to meet this case. The device of treating the wash on a separate pontoon has been suggested, but the Author has never heard of its being carried into practice. Heavy black sand frequently accompanies gold in alluvial ground. On the west coast of the South Island, New Zealand, certain dredging-claims exist which are sea-deposited and are even now only a few hundred yards from the sea. Here the gold is exceedingly fine, and black sand abounds, so that gold-saving operations are rendered exceedingly difficult. Some progress has been made recently, chiefly by using a large spread of tables, a good flow of water, and a distributing arrangement which makes every part of the table do its work. Large quantities of sand might also present another difficulty, as sand when run into the paddock behind the dredge might run in underneath it. In such a case arrangements might be made to elevate it to some distance away from the dredge.

The regularity or irregularity of deposits can only be ascertained by actual prospecting. The fact that the head of a creek has been drained by a race or by pumps, and has been worked for gold, does not prove that gold exists in the flat below, although, of course, it is an excellent indication. The "lead" of gold worked at the head of the creek may be only a lead running across the present creek bed, deposited by some previous water-course. The creek below may be almost barren until another cross-lead is met with. If the expense of accurately fixing the position of such runs of gold is not prohibitive, it should be done.

Every dredger must be built to suit all the requirements of the claim it is intended to work. Many claims have proved apparently valueless when worked by one dredger, which have afterwards given excellent returns when worked by a more suitable dredger. This has been due mainly to the fact that the first dredger was either not sufficiently powerful or else was unable to dredge deep enough, and had to leave the best part of the wash on the bottom untouched. In designing a dredger for any claim, it is always necessary to ascertain the greatest depth which it may be required to dredge. If the bottom is just so soft that it can be cleaned up easily, it may yet be uneven, or on a regular slope, and so cause difficulty. A ladder of such a length that it will dredge the deeper ground of a claim on being lowered until it approaches a vertical position, has, when in that position, the stresses supported at both ends. If, however, the same ladder be hauled up to dredge much shallower ground, it approaches a horizontal position, and, except for its weight, the principal working-stress will be in the direction

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of its length, and thus the stress will be sideways instead of downwards on the tumbler-frame which supports the upper end. In such a position the dredge will frequently "kick" as each bucket impinges against the face. To get rid of this trouble, ladders are sometimes made telescopic, so that they may be lengthened or shortened 4 feet or 5 feet. The deeper ground may be expected to carry more gold than the shallower ground; it should therefore not be missed.

Although a well-designed dredger will probably only need two men per shift, *i.e.*, six men, or eight men including the dredge-master and the engine-man, yet frequently roads to the ground must be made, and, if timbered, the timber must be cleared, and possibly cut up for firewood; the cost of labour, therefore, must not be dismissed without thought.

It may be possible to do away with expenditure in fuel by the use of electricity generated by water-power. Water-power has been used for dredges with good effect. If, however, steam has to be generated, the proximity and cost of coal or wood-fuel must be reckoned with. The cost of getting machinery on to the claim must receive as much consideration in dredging as in any other mining proposition.

The wash should not be too coarse, nor should it be excessively hard, due to cement; the proper coarseness is somewhat difficult to specify. Roughly, however, if the boulders do not exceed 18 inches in diameter, the ground is dredgeable. Occasionally boulders of 2 feet in diameter may be allowed, and although it has been stated that boulders of 10 tons weight have been lifted, they occasion serious inconvenience, and stoppages, if not breakages, will occur. However, it certainly seems that if the wash be coarse the gold has a tendency to be coarse also, and collected in pockets, so that it very frequently pays to move a large boulder, in order to recover what is underneath it.

Prospecting frequently constitutes a most expensive item, and nearly always a most unsatisfactory one. It has been said that the only way to prospect a river is to dredge it. Where that can be done it is undoubtedly a satisfactory test, but it is generally out of the question. Wing-damming is an expensive operation, and very liable to failure. Bore-holes have been put down in a river, but the Author does not consider boring-tests satisfactory. When it is considered that a bore-hole of 30 feet in length and 5 inches in diameter contains rather less than $\frac{1}{8}$ cubic yard, and that gold nuggets up to $\frac{1}{2}$ ounce in weight may easily be encountered, it is easy to see how misleading a boring-test may prove, and no one

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could expect to get any kind of accurate result. Should the gold be fine and the rods well managed, somewhat more reliable results may be obtained, but even then they cannot be expected to be more than a guide. To prove that gold exists in a claim, boring-machines are quite sufficient. An experienced borer with a good machine may obtain valuable information about a dry-land claim, and as he probably takes his own men with him wherever he goes, the danger from "salting" is minimized. If, however, some idea of the contents of the ground is required, then a shaft sufficiently large must be sunk, and drained either by pumps or by a drainage-race. The pump method is not always satisfactory, for with water streaming into a shaft it is quite possible that loose gold may be washed out of the walls, unduly enhancing the result.

Dredging procedure has been likened to a ready-developed mine in which the battery goes about and lifts the auriferous material *de situ*, but it suffers from one serious drawback from which battery practice is free. In a battery, a check on the battery manager is always possible through the medium of the assayer. It is not so in dredging, however, for it is absolutely impossible to sample the wash as it is lifted, and so the owners are absolutely dependent on the honesty of the dredge-master. That being the case, the dredge-master should for his own protection insist on one of the crew being in his presence all the time he is cleaning up, and before leaving the cabin the gold should be put in a bag, weighed, and sealed. So, too, a dredge-master is very dependent on the honesty of his crew. It is easy during a night-shift to place a handkerchief, spread out, on the table, and when lifted it leaves no mark.

The remarkable progress made in dredging in New Zealand during the last 5 years has been due in a measure to the excitement caused by the deserved success attending the efforts of a certain party of gentlemen in dredging the Molyneux River. This river has now been found, with the exception of a few miles, to be dredgeable for nearly its whole length, or about 100 miles, and as the river flows for about half its length through very rocky gorges, such a result is remarkable. The river flows from Lake Wakatipu, and, to give two instances of its character, its source is a fine waterfall, and about 35 miles below this is a natural bridge of rocks. So rocky is the Molyneux in parts that one dredge, built for convenience on an adjoining claim, was unable to dredge on to the right claim. A large number of claims, which were at their initiation termed "wild cats," are now proved successes.

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Judging by this, a prospector should not term a gorge undredgeable at first sight, for it is not unlikely that it may have a bottom composed of some kind of clayey material, which may prove very rich in gold. From the fact of a river having eaten its way through a rocky gorge, one concludes that it must have been flowing there for many years, and if it reaches the gorge after flowing through an alluvial flat, it is not unlikely that each mile of river-bed may be nearly equally rich in the total quantity of gold it contains, and that a mile of gorge may contain as much as a mile of flat; and if so, the wash in the gorge is concentrated so as to contain, bulk for bulk, much more gold than the flat. Dredging has been accomplished to a depth of 60 feet below water-level, and elevating to a height of 60 feet above it. These are extremes, and as the machines to do this work are very costly it is advisable to secure claims somewhat easier to work. At the same time a new type of elevator, in which centrifugal force is turned to profitable account, is now being tried, which, if successful, will greatly reduce the cost of elevators. In general, a depth of 35 feet and an elevation of 30 feet are quite convenient for a dredger to work.

Claims in New Zealand, which when prospected gave results of 6 grains, over 6 grains, and 1 dwt. to the cubic yard, respectively, have proved failures on dredging; in these cases the prospecting was probably tampered with. The Author, without going into details, believes that 3 grains per cubic yard will give, under favourable conditions, good results on 100 acres in New Zealand. There, a claim is nominally 100 acres, but generally not more than 70 acres of it is dredgeable, which may mean a life of about 8 years only, and during that time the first cost of the dredger must be paid, as well as a fair rate of interest on the capital expended.

The Author regards dredging as the most speculative of all mining industries, and, except under special circumstances, more suitable for private individuals than for large companies, and he ventures to assert that from its nature it will never attain the precision of battery and cyanide work.

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(*Paper No. 3349.*)

"The Flow of Water in Long Pipes."

By GEORGE MAXWELL LAWFORD, M. Inst. C.E.

IN order to compare the generally-accepted formulas for the flow of water in long pipes, and to test the results as calculated therefrom against those obtained from actual observation, the Author has selected as a basis for the comparison the fundamental formula of de Chezy:—

$$V = C\sqrt{RS}$$

V being the velocity in feet per second, C the coefficient of resistance, R the hydraulic mean radius, and S the slope of the water surface, or hydraulic mean gradient.

The value and terms of the coefficient of resistance differ materially in the formulas now in general use, and a short study of previous investigations shows that even at the present time there is considerable difference of opinion on the subject amongst the recognized authorities. The Author's experiments and investigations fully confirm the views of Professor Unwin, who, both in the article on Hydro-mechanics in the *Encyclopædia Britannica*, and in a concise article[1] in *Industries* (which has been reprinted in pamphlet form), defines the three principal causes of the variation of resistance as (1) the variation of velocity; (2) the variation of diameter; and (3) the variation of roughness of surface, *i.e.*, the physical condition of the interior of the pipe.

A comparison of the numerical values of the coefficient of resistance obtained from the selected formulas, with those obtained from actual observation, shows that none of these formulas is accurate for all sizes of pipes within the range of diameter of the pipes examined, but that certain formulas are applicable to pipes of particular diameters, and it therefore follows that either modifications must be made in the formulas to ensure a closer approximation to accuracy over the entire range, or a tabular series of coefficients should be determined which would give more accurate results

[1] "The Flow of Water in Pipes," *Industries*, vol. i. p. 51 *et seq.*

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with less complex calculations. The latter course has, in the Author's opinion, more to commend it than the former, and he has therefore adopted it in the following investigation.

The formulas selected for the purposes of comparison are those of Bazin, Crimp and Bruges, Darcy, Eytelwein, Hawksley, Kutter, Neville, Prony, Unwin, and Weisbach, which embrace the researches of both the earlier and the later investigators, and are given as applicable to clean, asphalted, cast-iron pipes, well jointed and laid under the ordinary conditions of water-mains, *i.e.*, at irregular gradients following the natural contours, with the usual proportion of bends, and with air-valves where necessary at summits. In the case of incrusted or tuberculated pipes, the velocity and discharge will vary according to the increased roughness of the interior surface of the pipe, and the reduction in diameter due to the incrustation. In the formulas of Kutter and Unwin this variation is met by assigning different values to the varying coefficients N and M, and in the simplified Darcy formula to the coefficients α and β. The head required to overcome friction at entry is disregarded, as in pipes of any considerable length, such as those referred to in the Table of selected experiments (Appendix, Table II.), it has been found to be inappreciable.

The following abbreviations are used in the formulas and throughout the Paper :—

V = velocity in feet per second.
D = diameter of pipe in feet.
R = hydraulic mean radius = $\frac{D}{4}$.
H = head of water in feet.
L = length of pipe in feet.
S = slope of water surface = hydraulic mean gradient = $\frac{H}{L}$ = sine of angle of inclination.
g = acceleration of gravity = 32·194 feet per second per second.
N = Kutter's coefficient for roughness of surface, ranging between 0·009 and 0·017.
M = Unwin's coefficient for roughness of surface, ranging between 0·0215 and 0·0440.
n = Unwin's exponential coefficient for variation of velocity, ranging between 1·72 and 2·00.
x = Unwin's exponential coefficient for variation of diameter, ranging between 1·10 and 1·390.
C = coefficient of resistance.
Q = quantity of water discharged, in gallons per minute.

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The following are the formulas investigated:—

Bazin formula—

$$V = \sqrt{\frac{RS}{0{\cdot}0000457\left(1 + \frac{0{\cdot}0984}{R}\right)}}$$

Crimp and Bruges formula—

$$V = 124\sqrt[3]{R^2}\sqrt{S}$$

Darcy formula—

$$V = \sqrt{\frac{R \times S \times 2g}{\zeta}}$$

$$\zeta = \left(0{\cdot}004346 + \frac{0{\cdot}0003992}{D}\right) + \left(\frac{0{\cdot}0010182 + \frac{0{\cdot}000005205}{D^2}}{V}\right)$$

Eytelwein formula—

$$V = \sqrt{\{(11704\,RS) + 0{\cdot}01698\}} - 0{\cdot}1303.$$

Hawksley formula—

$$V = 48\sqrt{\frac{DH}{L}}$$

Kutter formula—

$$V = \left\{\frac{41{\cdot}6 + \frac{1{\cdot}811}{N} + \frac{0{\cdot}00281}{S}}{1 + \left(41{\cdot}6 + \frac{0{\cdot}00281}{S}\right) \times \frac{N}{\sqrt{R}}}\right\}\sqrt{RS}$$

$$N = 0{\cdot}013.$$

Neville formula—

$$V = 140\sqrt{RS} - 11\sqrt[3]{RS}$$

Prony formula—

$$V = \sqrt{\{(9419{\cdot}7\,RS) + 0{\cdot}00665\}} - 0{\cdot}0816$$

Unwin formula—

$$V = \sqrt{\frac{S \times 2g \times D^x}{M}}$$

$$M = 0{\cdot}0254$$
$$n = 1{\cdot}85$$
$$x = 1{\cdot}127$$

Weisbach formula—

$$V = \sqrt{\frac{1}{0{\cdot}01439 + \frac{0{\cdot}017155}{\sqrt{V}}} \times \frac{D}{L} \times 2g \times H}$$

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All the foregoing formulas are easily applied by the use of logarithms. In the case of the Weisbach formula, however, the equation does not admit of a direct solution. An assumed value for $\sqrt{V}$ must be taken and the equation solved for V, from which $\sqrt{V}$ can be obtained. The value thus deduced must then be interpolated and the equation re-solved. An assumed value for V must also be taken in the Darcy formula unless the simpler form of equation, described later, is adopted, in which the variation of velocity is disregarded.

In order to compare the formulas, the Author has prepared a Table of coefficients (Appendix, Table I.) showing the relation between the results obtained by means of the ten selected formulas, the de Chezy formula being taken as the basis of comparison. A mean velocity of 3 feet per second has been assumed in the case of those formulas in which the numerical value of the coefficient is dependent either wholly or in part on the velocity, this rate of flow being that to which it is usually endeavoured to attain in designing and laying out waterworks, and also being a mean between the velocities of 1 foot per second and 5 feet per second, which, unless special conditions intervene, should be regarded as the limiting velocities. A graphic method of comparison is effected by plotting the numerical values of C, the abscissas denoting the various diameters of the pipes and the ordinates the values of C obtained from the curve for each formula, as shown in Fig. 1, Plate 7, in which the corresponding values for C obtained from the selected experiments are indicated by a dotted line. These values are given in the Appendix, Table I.

The numerical value of the coefficient of resistance has been closely investigated by Mr. Hamilton Smith, working on similar lines to those adopted by the Author, and the figures[1] arrived at by him are more in accord with the Author's results than those obtained from any of the foregoing ten selected formulas; in the following Table are shown the relative values of C when V = 3.

	Diameter in Inches.						
	12	18	24	30	36	42	48
Hamilton Smith .	109·0	116·0	121·0	125·0	128·0	131·0	134·0
Lawford	105·5	117·5	123·0	127·0	130·8	134·5	138·5

[1] "Hydraulics." By Hamilton Smith, Junr., p. 271. London, Trübner and Co. 1886.

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The Darcy formula is based on the well-known series of experiments published in "Recherches Hydrauliques"[1] but this formula is inapplicable to pipes of large diameter. The experiments were made with pipes varying between ½ inch and 20 inches in diameter, and for diameters greater than the latter the formula is inferential; moreover, the length of pipe experimented with was only 328 feet (100 metres) and the tests therefore partake somewhat of the nature of laboratory experiments. At the same time, as stated by Professor Unwin in the article in *Industries*, already referred to, the care with which the experiments had been carried out and recorded renders them absolutely trustworthy, as far as they go, and of great value to hydraulic engineers. To Darcy must be given the credit for having been the first to recognize the three causes of the variation of resistance, and more particularly that arising from the condition of the interior surface of the pipe. The formula as given previously is intended to embrace all classes and conditions of pipes, but a simplified form of equation, given by Professor Unwin in the *Encyclopædia Britannica*, is available, in which the variation of velocity is omitted and the coefficient is made binomial, the two terms being constants varying with the condition of the pipe and the diameter respectively. In the simplified formula—

$$\zeta = a\left(1 + \frac{\beta}{D}\right)$$

a being the term varying with the roughness of the interior surface and β that varying with the diameter. Darcy gives the following values for a and β:—

	a	β
For clean pipes	0·004973	0·084
„ incrusted pipes	0·00996	0·084

Bazin, who was associated with Darcy in his experiments, carried out a further series of investigations after Darcy's death, and extended the range of the Darcy formula, or rather put forward a modification of it which gives a closer approximation to the actual velocities and discharges in the larger-sized pipes. The value of Bazin's work is shown by the fact that his formula was adopted by the late Mr. J. F. La Trobe Bateman (Past-President Inst. C.E.), and was used in calculating the sizes of the large mains laid by him in various important undertakings. It is, however, noticeable that in the Bazin formula no allowance has been made for variation of velocity. This applies also to the

[1] *Imprimerie Impériale.* Paris, 1865.

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formula[1] put forward by the late Mr. Santo Crimp and his colleague Mr. C. E. Bruges. Their formula is constructed on similar lines to those of Darcy and Bazin, but the coefficient of resistance has a much wider range by reason of their having employed, instead of the expression $\sqrt{R}$, the value $\sqrt[3]{R^2}$. This formula has the merit of simplicity, and, regarded as a formula for mean velocity, is fairly reliable for rapid approximations.

The formulas of Eytelwein and Prony are both founded to a certain extent on experiment, and reproduce the work and results of the earlier hydraulic engineers, Du Buât, D'Aubisson, Couplet, and Bossut. In both of these formulas, as well as in those of Neville and Weisbach, the numerical value of the coefficient of resistance is dependent solely on the velocity, and is not affected by variation of diameter or condition of surface; whilst the Hawksley formula stands alone with a coefficient which is constant under all conditions.

It has been left to Kutter and Unwin to develop and advance formulas which embody the combined results obtained by the two classes of formula in which the coefficient is dependent on the diameter and on the velocity respectively, and at the same time to recognize the researches of Darcy and to investigate the third, and by no means the least important, cause of variation, namely, the condition of the internal surface of the pipe. Both formulas are based on or deduced from experiments, but whilst the Kutter formula gives a closer approximation to actual results for the smaller pipes, the Unwin formula is better for the larger sizes. Kutter adopts the de Chezy type of formula, and, as the result of a very large number of experiments and investigations on open channels by himself and his colleague, Mr. Ganguillet, deduces a formula applicable to pipes, and gives a trinomial expression for the coefficient which comprises the three causes of variation. The results obtained by calculation from the Kutter formula, are, to a considerable extent, dependent on the value assigned to the coefficient N, the range of which, although numerically small (between 0·009 and 0·017), affects the velocity, and consequently the discharge, in a very marked degree. This value has been closely investigated by Mr. Rudolph Hering, and also by Messrs. E. B. Taylor[2] and G. M. Taylor, who, as the result of a very large

[1] "A New Formula for the Flow in Sewers and Water-mains." By W. Santo Crimp, M. Inst. C.E., and C. E. Bruges, Assoc. M. Inst. C.E., Minutes of Proceedings Inst. C.E., vol. cxxii. p. 198.

[2] "Water-Pipe Discharge Diagrams." By E. B. Taylor, M. Inst. C.E., and G. M. Taylor, Assoc. M. Inst. C.E. London, Bataford, 1891.

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number of determinations, based on actual measurements chiefly on the mains of the Lambeth and Bristol waterworks, have adopted the value for N of 0·013 for new or clean asphalted cast-iron pipes laid under ordinary conditions. Messrs. Crimp and Bruges, in the Paper previously referred to, also give the same value, and the Author has therefore adopted it in calculating the values of C given in the Appendix, Table I., and plotted in Fig. 1, Plate 7.

Professor Unwin adopts the Hagen modification of the St. Venant formula, in which—

$$\frac{H}{L} = \frac{MV^n}{D^x}$$

M, x, and n being coefficients derived from experiment. Professor Unwin introduces the term $2g$, giving the formula—

$$\frac{H}{L} = \frac{M \times V^n}{D^x \times 2g}$$

and assigns numerical values to the three coefficients, which he has deduced from practice, for the different classes of pipes. This formula, besides being simpler than the Kutter formula for practical calculations, has one distinct advantage, which is best expressed in the formulator's own words, viz.: "that the three coefficients can be taken so as to allow separately for the three causes of variation." While agreeing with the numerical values assigned to M and n, the Author finds that an expansion of the term D^x would bring about a closer approximation to the observed results as tabulated in the Appendix, Table II., and would enable the formula to be used with accuracy over the entire range of the usual sizes of water-mains, namely, between 3 inches and 48 inches, or even more, in diameter. It will be seen, by reference to the Appendix, Table I., and to the curves in Fig. 1, Plate 7, that the values of the coefficient of resistance C, obtained by Professor Unwin, range, in round numbers, between 100 and 120, whilst those obtained by the Author range between 70 and 140, from which it would appear that the variation of diameter in the former is insufficient, and that the term D^x requires contraction for the smaller pipes and expansion for the larger. This could apparently be effected by making x differential, with values ranging between 0·492 for 3-inch pipes and 1·343 for 48-inch pipes. Calculating these values for the range of diameters mentioned, the mean value of x is found to be 1·127, which is the

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constant value assigned to it by Professor Unwin, who demonstrates that "the index x of D in the formula for loss of head, must be greater than unity." Retaining x as a constant with the value 1·127, the Author finds that the desired modification may be effected by multiplying D^x by a coefficient which varies with the diameter, giving the following modified formula :—

$$\frac{H}{L} = \frac{M \times V^n}{F D^x \times 2g}$$

and for velocity—

$$V = \sqrt[n]{\frac{S \times 2g \times F D^x}{M}}$$

The mean values of the coefficient F are given in the following Table :—

Diameter of Pipe.	F.	Diameter of Pipe.	F.
Inches.		Inches.	
3	0·492	27	1·191
6	0·673	30	1·214
9	0·821	33	1·240
12	0·941	36	1·252
15	1·038	39	1·285
18	1·106	42	1·306
21	1·138	45	1·327
24	1·165	48	1·343

These values are also shown graphically in Fig. 2, Plate 7, from which the value of F for any of the intermediate sizes of pipes can be readily obtained. The coefficient F is not absolutely constant for each diameter, but varies to a very slight extent with the velocity, the variation being in direct ratio for pipes up to 15 inches diameter, and in inverse ratio for pipes of larger diameter. The range, however, is very limited, and the variation of F for velocity is practically inappreciable and need not be taken into consideration.

Professor Unwin gives a simplified form of equation, viz., $\frac{H}{L} = \frac{K}{D} \times \frac{V^2}{2g}$, in which K is trinomial, being deduced from the three coefficients M, n and x in the original formula. The values of K, as given for asphalted cast-iron pipes, range between 0·0257 for pipes of 6 inches to 9 inches diameter at velocities of 1 foot to 2 feet per second, and 0·0173 for pipes of 36 inches to 48 inches diameter at velocities of 4 feet to 5 feet per second. As this is virtually a reduction to the de Chezy form of equation, the

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extended values of K to make the formula fit the Author's determinations can be obtained from the expression—

$$K = \frac{8g}{C^2}$$

the values of C being taken from Fig. 3, Plate 7, or from the corresponding Table (Appendix, Table III.).

The nature of the coefficient affords a simple and convenient means of classifying the formulas.

Hawksley formula	The coefficient is a monomial constant.
Bazin formula Crimp and Bruges formula	The coefficient is monomial, varying with the *diameter only*.
Eytelwein formula Neville „ Prony „ Weisbach „	The coefficient is monomial, varying with the *velocity only*.
Darcy (simplified) formula	The coefficient is binomial, varying with the diameter and roughness of surface.
Darcy (general) „ Kütter formula Unwin „	The coefficient is trinomial, varying with the diameter, the velocity, and the roughness of the surface.

The de Chezy formula is frequently expressed in the following form :—

$$\zeta \frac{V^2}{2g} = \frac{D}{4} \times \frac{H}{L}$$

which gives a value for C in the formula for velocity of $\sqrt{\frac{2g}{\zeta}}$, the value of ζ varying with the diameter of the pipe, as exemplified in the formulas of Bazin and Crimp and Bruges, and with the velocity and roughness of surface as exemplified by the Darcy formula. The range of coefficients for roughness of surface examined by Darcy was, however, small, and the variation of diameter as shown in Fig. 1, Plate 7, and in the corresponding Table (Appendix, Table I.), is altogether insufficient. A brief reference to the Table of selected experiments (Appendix, Table II.) affords a practical confirmation of the investigations of Darcy, Kutter and Unwin, and proves conclusively that those authorities were right in evolving formulas in which the coefficient of resistance contains three terms.

The de Chezy formula could be modernized by making ζ or C trinomial, the three terms being functions of R and S, with a numerical coefficient for roughness of surface, but the calculations required to produce such a result would be necessarily of a complex character, and would cover ground already thoroughly gone over by Darcy, Kutter, and Unwin.

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In selecting experiments for the purposes of this investigation, the Author's attention was directed to the scarcity of reliable data obtainable from water-companies and waterworks engineers in this country, and he has consequently had to rely to a great extent on the records of American and German engineers. A circular letter to the engineers of the eight London water-companies elicited the somewhat remarkable fact that, with one exception, there was no reliable information on the subject of flow in pipes in the possession of the companies, which could be of actual utility. The records of the American and German engineers who have studied this question have been thoroughly examined, in order to exclude all anomalous results and to deal only with observations which are comparable with one another, and the accuracy of which may be relied upon; the experiments were made on mains in actual use, the pipes being of cast iron, asphalted or tarred, and either new or clean and free from incrustation or corrosion.

The series of experiments made by the Author on small pipes were made on mains which had been in use for one or two years; the condition of the internal surface was noted as well as bends and local conditions likely to affect the flow. The relative heights of the inlets and outlets under examination, and of the hydrostatic water-levels, were carefully taken and reduced to Ordnance datum, and the various lengths were accurately measured. The velocities were determined by volumetric observations, arrangements being made in each set of experiments to measure the discharge into or out of a compartment of a covered service-reservoir, of which there were three available, and of which the actual dimensions had been ascertained and checked. The Author also noted the temperature of the water at the inlet and at the outlet, of the atmosphere, of the earth and of the pipe itself. The effects of temperature are, however, so slight that they need not be taken into consideration in calculations for practical purposes. The results of the various experiments on small pipes show that the coefficient of resistance has a wider range of variation with the velocity than in the case of larger mains, and it is doubtless due to this fact having been overlooked, or not sufficiently recognized, that the greater number of formulas, more particularly the earlier ones, are unreliable, and in the case of pipes of small diameters give results differing very widely from actual observations. This variation is exemplified by the curves in Fig. 3, Plate 7, the difference between the values of the coefficient increasing as the diameters decrease.

A valuable addition to the list of reliable records of experiments

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on mains of large diameter is that of the experiment by Mr. Walter Hunter, M. Inst. C.E., on the intercommunicating main of the Grand Junction and New River Companies between Kew Bridge and New River Head. This main was laid in 1898, and the flow through it was measured in September, 1899, by a "Venturi" meter, in Oxford Street, and also over a weir at the New River Head, the meter- and weir-measurements agreeing within about 1 per cent. The total length of main was 17,388 yards, of which an intermediate length of 4,454 yards was 30 inches in diameter, the remainder being 24 inches in diameter. There were about fifty-eight bends along the course of the main, which followed the natural irregularities of contour. Water was pumped at Kew Bridge to a height of 184·5 feet above Ordnance datum, and delivered into a tank at New River Head at 98·37 feet above Ordnance datum, thus giving a net head of 86·13 feet, and a hydraulic mean gradient of 1·65 in 1,000. The quantity of water delivered under these conditions was 6,239,600 gallons per 24 hours, which gives a velocity of 3·231 feet per second through a pipe of 25·6 inches mean diameter. For pipes of 24 inches and 30 inches diameter, with the same hydraulic mean gradient, the velocities would be 3·59 feet per second and 4·206 feet per second respectively, and the corresponding values of C would be 125 and 130·97 respectively.

In 1899, an experiment was made by Mr. Haynes on the 30-inch main of the Manchester Corporation Waterworks, between the Godley and Audenshaw reservoirs. The length of main experimented on was 22,155 feet, and the hydraulic mean gradient was 6·14 in 1,000. The gradient was very irregular, with air-valves at summits. The main had been 2 years under construction, and the experiment was made after 2 months' use, the pipe being clean and free from corrosion. The discharge as measured was 19,800,000 gallons per 24 hours, which gave a velocity of 8·381 feet per second, and a value for C of 135·31.

Previous writers on this subject have frequently referred to the experiment by Mr. J. M. Gale, M. Inst. C.E., on the 48-inch main forming a section of the Loch Katrine supply to Glasgow, and, because his results agreed with the Darcy formula, have erroneously inferred the correctness of this formula. The Author is of opinion, however, that, although Mr. Gale's measurements are entitled to the most careful consideration, some unknown source of error must have been present. Three independent sets of data for pipes of this size are now available, and such corroborative testimony must be deemed conclusive; the Author has therefore excluded Mr.

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Gale's results and has accepted those of Messrs. F. P. Stearns, D. Fitzgerald and A. F. Bruce, M. Inst. C.E., which are tabulated in the Appendix, Table II. The value of C calculated from these three series of experiments for a velocity of 3·5 feet per second is 139·5 as against Mr. Gale's 112·5, or a difference of 25 per cent. Further evidence is adduced by the fact that the value of C is over 112 for pipes of 15 inches diameter, and continues to increase, until the 48-inch pipes are reached, which are the largest pipes mentioned in the Table. From the values of C calculated from the results of the selected experiments the curves shown in Fig. 3, Plate 7, were determined. The values of S (hydraulic mean gradient) which produce the five given velocities are shown graphically in Fig. 4, Plate 7; and a series of curves showing the velocity, inclination and discharge for pipes up to a maximum diameter of 48 inches and a maximum velocity of 5 feet per second, deduced from the tabulated experiments, is given in Figs. 5–8, Plate 7.

The values of C given in the Appendix, Table III., may be employed to facilitate hydraulic calculations by means of the following simplified formulas:—

$$V = C\sqrt{RS} \qquad Q = C\sqrt{R^5 S} \times 14695{\cdot}7$$

$$R = \frac{V^2}{C^2 S} \qquad D = 4\left(\frac{V^2}{C^2 S}\right)$$

$$H = \frac{V^2 L}{C^2 R} \qquad L = \frac{C^2 R H}{V^2}$$

$$S = \frac{V^2}{C^2 R}$$

In conclusion, the Author would submit that accurate results can be obtained for the flow of water through new or clean cast-iron asphalted pipes either by the use of the fundamental formula in conjunction with a trinomial coefficient as exemplified in the Paper, or by the use of the Unwin-Hagen formula as modified; and he desires to thank Professor W. C. Unwin, F.R.S., M. Inst. C.E., Mr. William Fox, M. Inst. C.E., Mr. Walter Hunter, M. Inst. C.E., and Mr. J. Haynes for information kindly given, and also his assistants, Messrs. H. Wontner-Smith, Stud. Inst. C.E., and F. H. Hodson, for their co-operation in checking the large number of calculations involved, and in the preparation of the diagrams which accompany the Paper.

The Paper is accompanied by eight tracings, from which Plate 7 has been prepared, and by the Tables given in the following Appendix.

[APPENDIX.

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APPENDIX.

TABLE I.—COMPARATIVE VALUES OF C WHEN V = 3.

	Diameter of Pipe in Inches.											
	3	6	9	12	15	18	21	24	30	36	42	48
Bazin	92·2	110·7	119·8	125·3	129·0	131·7	133·7	135·2	137·5	139·1	140·3	141·1
Crimp and Bruges	78·1	87·7	93·8	98·4	102·1	105·3	108·0	110·5	114·7	118·2	121·3	124·0
Darcy	98·5	105·3	107·9	109·3	110·1	110·7	111·1	111·5	111·9	112·2	112·5	112·6
Eytelwein	103·8	103·8	103·8	103·8	103·8	103·8	103·8	103·8	103·8	103·8	103·8	103·8
Hawksley	96·0	96·0	96·0	96·0	96·0	96·0	96·0	96·0	96·0	96·0	96·0	96·0
Kutter	57·8	69·6	78·5	85·3	90·2	94·4	97·9	101·1	106·0	110·1	113·4	116·5
Lawford	70·0	86·0	97·0	105·5	112·5	117·5	120·5	123·0	127·0	130·8	134·5	138·3
Neville	104·1	104·1	104·1	104·1	104·1	104·1	104·1	104·1	104·1	104·1	104·1	104·1
Prony	94·5	94·5	94·5	94·5	94·5	94·5	94·5	94·5	94·5	94·5	94·5	94·5
Unwin	100·1	104·6	107·4	109·4	110·9	112·2	113·3	114·3	115·9	117·3	118·4	119·4
Weisbach	103·0	103·0	103·0	103·0	103·0	103·0	103·0	103·0	103·0	103·0	103·0	103·0

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TABLE II.—SELECTED EXPERIMENTS.

Diam.	S.	V.	C.	Authority.
Inches.	s			
3	0·00597	1·121	58·01	G. M. Lawford, Curry Rivel Waterworks, 1900–01. Cast-iron pipes; asphalted; 1 year in use; clean; slope fairly uniform. Length, 5,790 feet.
,,	0·01492	1·983	64·93	
,,	0·03078	3·080	70·22	
,,	0·05361	4·492	77·60	
,,	0·05760	4·961	79·88	
4	0·00223	0·928	68·11	G. M. Lawford, as above. Slope irregular with air-valves at summits. Length, 18,720 feet.
,,	0·00377	1·231	68·40	
,,	0·00548	1·514	70·83	
,,	0·00927	2·015	72·51	
4	0·02629	3·661	78·22	G. M. Lawford, as above. Slope uniform. Length, 8,800 feet.
,,	0·03043	4·110	81·62	
,,	0·04028	4·981	85·97	
,,	0·04554	5·490	89·12	
5	0·01436	3·218	83·21	G. M. Lawford, as above. 2 years in use; clean; slope uniform. Length, 5,140 feet.
,,	0·02086	4·014	86·11	
,,	0·02717	4·897	89·96	
,,	0·03051	5·131	91·03	
6	0·00459	2·000	83·50	Iben, Hamburg Waterworks, 1876. Cast-iron pipes; asphalted; new. Length, 1,073 feet. ("Druckhöhenverlust.")
,,	0·01162	3·300	86·59	
,,	0·01621	3·900	86·64	
,,	0·02282	4·800	90·87	
,,	0·01810	4·700	91·48	E. B. Weston, Providence Waterworks, U.S.A., 1876–77. Cast-iron pipes; asphalted; 4 years in use; clean. Length, 1,171 feet. (Transactions, American Society of Civil Engineers, vol. xxii.)
,,	0·04069	7·250	101·66	
,,	0·05591	8·490	103·93	
8	0·00038	0·780	91·75	Ehmann, Stuttgart Waterworks, 1878. Cast-iron pipes; asphalted; 4 years in use; clean. Length, 810 feet. (Iben, "Druckhöhenverlust.")
,,	0·00085	1·120	94·12	
,,	0·00133	1·450	97·41	
12·05	0·00121	1·568	90·17	Bonn Waterworks, 1880. Cast-iron pipes; asphalted; new. Length, 17,684 feet. (Iben, "Druckhöhenverlust.")
,,	0·00195	2·104	95·22	
,,	0·00269	2·595	99·84	
,,	0·00362	3·096	102·72	
16·48	0·00059	1·577	110·46	Dr. Lampe, Dantzig Waterworks, 1869–71. Cast-iron pipes; asphalted; 5 years in use; clean. Length, 31,719 feet. ("Der Civilingenieur," 1873.)
,,	0·00138	2·482	114·19	
,,	0·00163	2·709	114·53	
20	0·00012	0·700	99·19	Iben, Hamburg Waterworks, 1876. Cast-iron pipes; asphalted; new. Length, 3,514 feet. ("Druckhöhenverlust.")
,,	0·00048	1·600	113·36	
20	0·00073	2·000	114·99	C. B. Brush, City of Hoboken Waterworks, U.S.A., 1882. Cast-iron pipes; coated with tar; 5 years in use; clean. Length, 75,000 feet. (Transactions, American Society of Civil Engineers, vol. xix.)
,,	0·00088	2·240	117·48	
21	0·00139	2·957	119·97	C. A. Friend, Seville Waterworks, 1894. Cast-iron pipes; asphalted; 7 years in use; clean; slope fairly uniform. Length. 42,050 feet. (Minutes of Proceedings Inst. C.E., vol. cxix.)
	0·00151	3·105	121·26	

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TABLE II.—*continued.*

Diameter.	S.	V.	C.	Authority.
Inches.				
24	0·00165	3·590	125·00	W. Hunter, Grand Junction and New River Waterworks, 1899. Cast-iron pipes; asphalted; new. Length, 38,802 feet. (Communicated.)
30	0·00102	3·08	121·99	C. G. Darrach, Philadelphia Waterworks, U.S.A., 1878. Cast-iron pipes; asphalted; 2 years in use; clean. Length, 4,000 feet. (Transactions, American Society of Civil Engineers, vol. vii.)
,,	0·00108	3·23	124·32	
30	0·00165	4·206	130·97	W. Hunter, Grand Junction and New River Waterworks, 1899. Cast-iron pipes; asphalted; new. Length, 13,362 feet. (Communicated.)
30	0·00614	8·38	135·31	J. Haynes, Manchester Waterworks, 1899. Cast-iron pipes; asphalted; new; gradient irregular. Length, 22,155 feet. (Communicated.)
48	0·00020	1·908	136·01	A. F. Bruce, Blane Valley Siphon, Glasgow Waterworks, 1895. Cast-iron pipes; asphalted; laid 2 years, in use 2 months. Length, 3,557 feet. (Minutes of Proceedings, Inst. C.E., vol. cxxiii.)
,,	0·00071	3·649	137·65	
48	0·00071	3·740	140·17	F. P. Stearns, Rosemary Siphon, Boston Waterworks, U.S.A., 1879. Cast-iron pipes; asphalted; new. Length, 1,800 feet. (Transactions, American Society of Civil Engineers, vol. xiv.)
,,	0·00122	4·964	142·12	
,,	0·00185	6·194	144·01	
48	0·00071	3·734	139·94	D. Fitzgerald, 1893. Pipe last described after 14 years' service; pipes scraped clean, and then experimented on. (Transactions, American Society of Civil Engineers, Vol. xxv.)
,,	0·00122	4·951	141·74	
,,	0·00185	6·158	143·16	

TABLE III.—VALUES OF "C" FROM EXPERIMENTS.

Diameter.	V = 1.	V = 2.	V = 3.	V = 4.	V = 5.
Inches.					
3	58·0	65·0	70·0	75·0	80·0
6	75·0	80·6	86·0	90·0	94·2
9	87·2	92·2	97·0	101·0	105·0
12	97·0	101·5	105·5	109·0	112·5
15	104·8	108·8	112·5	115·2	118·2
18	110·5	114·5	117·5	119·8	122·2
21	114·0	118·0	120·5	123·0	125·0
24	116·2	120·0	123·0	125·5	127·6
27	118·2	122·0	125·2	127·5	129·7
30	120·2	124·0	127·0	129·2	131·4
33	122·3	126·3	129·0	131·1	133·2
36	124·5	128 0	130·8	133·0	135·0
39	126·5	130·0	132·8	134·8	136·8
42	128·5	132·0	134·6	136·8	138·5
45	130·5	134·0	136·4	138·5	140·2
48	132·5	136·0	138·3	140·2	142·0

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(Paper No. 3377.)

"Work done in the Orange River Colony Refugee Camps."

By HENRY C. TROLLOPE.

THE Orange River Colony refugee camps were handed over by the Military Authorities to the Civil Government as from 1 February, 1901, on which date the total population in all the camps was about 7,000 persons. At that time it was anticipated that the refugees would have to be maintained for only a few months longer, and consequently any considerable works were deemed unnecessary, especially for so small a population. A few months' experience, however, put a different complexion both on the duration of the camps and on the population limits, and when, towards the latter end of 1901, the number of refugees increased to 45,000 in the thirteen camps—additions of 1,000 to 2,000 persons sometimes occurring in a single day—difficulties arose in providing them with certain necessaries of life, including water, the country being apparently devoid of any quantity of it, except near the rivers on its boundaries. The camps were also at a disadvantage in the absence of buildings near them which could be used for hospitals and other purposes, and it would appear that, even with the best kind of tent, it was impossible to treat certain diseases with success.

Early in October, 1901, the Author was appointed Inspector of Works for the camps of this Colony, with instructions particularly to improve the water-supplies at some of the larger camps. Nearly all the camps were having water carted to them from sources at distances varying between about 1 mile and 2 miles or more, and, with populations of 3,000 to 6,000 persons to provide for, a considerable number of carts and animals were constantly employed from daylight to well into the night, with the result that perhaps barely 1 gallon of water per day reached each person for all purposes. Water has now been led in pipes to six camps in all. Schemes for supplying two other camps were sanctioned at the time peace was declared, but it is probable that these will not now

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be required. The water-supplies at Kroonstad (population 3,600) and Winburg (population 3,000), were the first taken in hand.

Kroonstad Water-Supply.—The Kroonstad camp is favoured in situation as it lies in a bend of the Valsch River where there is a small stream flowing even in the seven or eight months when no rain of importance is expected. The water, however, is heavily charged with silt, rendering it unfit for drinking purposes. The camp drinking-water used to be carted from a stand-pipe near the town reservoir, about 2 miles from the centre of the camp. The reservoir water had passed through a sand filter-bed which was somewhat defective owing to the large number of persons drawing from it, the refugees and military having suddenly trebled the normal population of Kroonstad; it was still, however, of much better quality than the silty river-water. A line of levels to this reservoir showed a fall of 99 feet to the highest point in the camp, and accordingly a 2-inch galvanized-iron pipe was laid, branching to various points in the camp, with stand-pipes and taps at convenient places, Figs. 1 and 2, Plate 8. It was expected that a supply of 15 gallons per minute would reach the camp, and fully this quantity is received; being about 3 gallons per head of population in 12 hours, it is found ample for drinking and cooking purposes. To avoid interference with the town main, the water was siphoned over the reservoir-wall, 12 feet in height, an air-vessel charged with water being placed on the highest point, and this has worked satisfactorily. Near the lowest point in the valley intervening between the reservoir and the camp a short branch-pipe is laid, having a valve at its extremity, so that sediment collecting there may be flushed out of the pipe occasionally. Exclusive of digging the trench, about 1 foot 6 inches in depth, the actual laying of the 8,400 feet of 2-inch pipe, with the meter and other connections, occupied 8 days. The pipes were laid from the reservoir end, and were tested for leaks about every 100 yards; no leaks of any importance were discovered. The greatest pressure at any point is 47 lbs. per square inch.

As is usually the case in refugee camps, the work was carried out by burgher refugees with only one skilled man to supervise. The twenty men employed were sufficient for trench-digging, screwing pipes and filling in. Boiled water is supplied during the greater part of the day from four 400-gallon tanks set in brickwork connected to the water-supply, and placed in different parts of the camp. Water for washing clothes and for bathing was also required, the latter more especially since, owing to the shifting sandy bed of the Valsch (false) River, several refugees

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had been drowned in it while bathing. Near the camp the river runs in a trough fully 50 feet in depth, and the washing-water is pumped from it to storage-tanks on the top of the bank by an Evans geared horizontal pump, driven by a belt from a Crossley oil-engine. The site of the pump is excavated in the bank, and the pump is placed 26 feet above the normal low-water level of the river, Fig. 3, Plate 8. This appears to be about the limit at which a suction-pump will work at this altitude (4,500 feet above the sea-level) as, although it works satisfactorily, the pipe-joints have to be perfectly air-tight. The pump is only 2 feet above the level of a particularly high flood which occurred in 1901, and it is possible that an abnormal flood may yet reach it. The pump is, however, well anchored, and will probably not be carried away even if temporarily submerged. It delivers 2,000 gallons per hour and is running during the greater part of the day.

The waste-water from wash-houses and baths is used to irrigate vegetable gardens for the use of the camp, thus saving the cost of bringing vegetables from the coast, the only other source of supplies of this nature. Clothes are washed in zinc-lined troughs 12 feet in length by 4 feet in width, and the bathing-house consists of a range of rooms 6 feet square, with a bath, tap, and shower, above concrete floors. The Kroonstad water-supply cost about £1,000.

Winburg Water-Supply.—The finding of sufficient water for the wants of the Winburg camp presented difficulties owing to the fact that any considerable quantity was not visible within 5 miles of it. Several hundred feet of boring by diamond-drill had resulted in complete failure to find water near the camp, and there remained a small spring in a kloof (a division between two hills) about ¾ mile from the camp, and what water could be spared from the well, about the same distance away, from which the town and the military were supplied.

The kloof spring gives about 2,000 gallons per 24 hours, and by leading it round a hillside there was no difficulty in gravitating it to the camp, as shown in Figs. 4 and 5, Plate 8. A pipe of ample size for this quantity discharged into iron storage-tanks having a total capacity of 4,000 gallons, placed on high ground commanding the camp. The level of the town well being 91 feet below that of the storage-tanks, an oil-engine and pump were erected on concrete foundations a short distance from it, and the water from this source is also delivered into the storage-tanks, but as the delivery-pipe passes through the centre of the camp it is branched in several directions to stand-pipes where required, the

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surplus water not actually used while pumping is in operation being stored in the tanks. The pump delivers 2,000 gallons per hour, and it empties the well in 3 hours. The well is apparently supplied by a fairly strong spring, as, in spite of being pumped dry daily, it still continues to supply the town of Winburg and the troops quartered there, in addition to the refugee camp of 3,000 persons. The cost of the Winburg water-supply was also about £1,000.

Water-supply to other Camps.—The four other camps, viz., Brandfort, Bloemfontein, Springfontein and Bethulie, to which water has been led, have, in general, been supplied by means similar to those adopted either at Kroonstad or at Winburg. The sources of water at Brandfort, Bloemfontein and Springfontein are wells, bored with a diamond-drill 3 inches to 4½ inches in diameter, on which pumps, generally of the Gould deep-well type, are fixed, and driven either by steam- or oil-engines; the two wells at Springfontein are not more than ¼ mile distant from the camp, while those at Brandfort are, on an average, ½ mile from the camp, and the water at Bloemfontein is pumped for a distance of 2 miles by an oil-engine and a Worthington steam-pump. At Bethulie a well 10 feet square and 24 feet in depth, with a bore-hole 30 feet in depth in the bottom of it, was dug at a spot 1,200 yards from the camp, and an inexhaustible supply of water was obtained, and pumped by an oil-engine and double-barrelled pump. Altogether eight Crossley oil-engines, two steam-pumps, one hot-air engine and one windmill, besides twenty hand-pumps, are employed for raising water. A few horse-gears are provided in case of a break-down in the power-plants. The windmill is of American construction, and has a 10-foot wheel and a 30-foot steel angle-bar tower. It has worked satisfactorily, and many more of these mills would have been erected but for the fact that the risk of calm days greatly increased the storage necessary. A few earthen dams with stone-pitched slopes have been constructed, chiefly to provide bathing and washing-water. These dams are similar to those to be seen at all the farm homesteads, and they appear to be fairly durable. The banks are chiefly made by scrapers drawn by oxen. There is a tendency among the Boers to be too sparing in the material of the inner slope, which is usually only 1½ to 1.

Boring for water in this colony is generally attended with success, due to the fact that the country is intersected by intrusive dykes of igneous rock (diorite) which serve as underground reservoirs, and there is not much difficulty in selecting a site for boring, provided the dip and strike of these dykes can be located. A

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bore-hole 3⅛ inches in diameter on a good site yields between 400 gallons and 500 gallons per hour. Experience seems to indicate that the water obtained from the bore-wells is only soakage from the ground in the near neighbourhood, and does not usually penetrate more than 300 feet below the surface. The supply of water varies both in quantity and permanence according to the catchment-area and the dip of the underlying strata. During the dry months of the year some wells have been practically exhausted, while the level of the water standing in others has receded as much as 15 feet. No improvement is noticeable until about 2 months after the heavy rains commence, in January. The Orange River Colony has not yet been thoroughly prospected for minerals; but the boring and digging done at the refugee camps revealed little in this respect. The usual formation passed through consists of alternate layers of sandstone and compact and laminated shales, the latter being generally water-bearing. Recently, in boring for water on Bloemfontein commonage, a 6-inch layer of conglomerate, similar to that at Johannesburg, embedded in sandstone, was passed through, but it is not yet known whether it is gold-bearing. Carboniferous shales are penetrated in the north of the Colony, but not frequently south of Kroonstad.

The buildings erected in the camps include living-huts for refugees (in place of tents), hospitals, dispensaries, quarters for the nursing-staffs, store-rooms, ration-sheds, workshops for the different trades, school buildings, churches and recreation-halls. With the exception of hospital buildings, built by contract owing to the urgency of the case, the whole of the camp-buildings, whether of stone, brick, or wood and iron, have been erected by burgher tradesmen and labourers. Owing to the difficulty of obtaining transport of materials from the coast, due to an insufficient number of railway-trucks and to the cost of timber, very great economy has been exercised in the quantities used. Roof principals for spans as wide as 30 feet are often of wood, 4½ inches by 1½ inch, bolted together, the wall-studs being of the same size. Some of the roofs have been braced diagonally with 1-inch boards, and fortunately the corrugated-iron covering has a stiffening effect. Whilst these buildings are, perhaps, somewhat lighter than is advisable, the Author is confident that in buildings sent from England for re-erection in the Colony, there is more than twice the necessary quantity of timber in the frames, causing increased expenditure in first cost and in carriage over about 1,000 miles of railway.

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The living-huts are of a variety of forms, partly in accordance with the materials available in the different localities. The most substantial are rows of four rooms, 14 feet square, at Kroonstad, built of large sandstones, roughly dressed, with chisel-dressed quoins. The walls are plastered inside with the red ground usually employed in the colony, and it is both cheap and satisfactory. These stone buildings were erected at a time when water for brick-making was scarce. Some two-roomed huts, about 24 feet by 12 feet, at Brandfort, are probably the most satisfactory. The walls of these are of sun-dried bricks, 12 inches by 9 inches by 5 inches, and they are roofed with iron. They were built at the rate of three huts in 2 days, complete with doors, window-openings and fire-places. A few huts in this camp have been built in burnt brick, the number being limited by the scarcity of fuel for the kilns. Where the ground was unsuitable for brick-making, as, for example, at Orange River, wood-framed huts have been built, but the brick buildings are the most comfortable both in summer and winter. Some hospital wards have been built of bricks by the refugees, but such buildings are mostly wood-framed and iron-covered, 90 feet in length by 20 feet in width, floored and lined, and have hot-water heating-apparatus and a kitchen attached. The school-buildings, accommodating altogether over ten thousand children, have generally brick walls, the gable ends being left open for ventilation. The whole of the baking is done in public brick ovens, some of which are ranges 8 feet in diameter, of the circular-dome class used by the military. These are, however, difficult to build, and the ordinary rectangular baker's oven with an arch springing from the sides and back, and having cast-iron grate-bars and wrought-iron doors, is now adhered to. In each camp 2,000 to 3,000 pints of soup are served daily, made in ranges of cast-iron boilers, 2 feet 6 inches in diameter, set in brickwork, in kitchens specially built for the purpose.

With a view to provide employment for refugees who might be otherwise destitute on the breaking-up of the camps, the Chief Superintendent has, from the beginning, encouraged the learning of trades likely to be useful, and buildings and tools have been provided where required. The trades worked at include brick-making and laying, stone-masonry, carpentry, turning, blacksmithing, wagon-making and boot-making, and these trades have all been carried on with a considerable degree of success. The fostering of these trades, combined with the purchase of materials in large quantities, has resulted in a decided saving to the Government, the bulk of the works and buildings having

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been carried out by refugees for less than two-thirds of what they would have cost by contract.

In conclusion, it is the Author's opinion that, apart from the increased supplies obtained, the capital expended on leading water to these camps has already been repaid in the saving of the transport animals formerly employed, and, although there will be certain losses in connection with brick buildings, it is anticipated that the whole of the timber and sheet-iron will find a ready sale on the breaking-up of the camps.

The Author is indebted to Colonel J. S. Wilkins, I.M.S., Chief Superintendent of Refugee Camps, Orange River Colony, for permission to submit the foregoing brief summary of works undertaken in these camps.

The Paper is accompanied by two tracings, from which Plate 8 has been prepared.

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OBITUARY.

HORACE BELL was born in London on the 17th June, 1839, and was educated in France and at Louth in Lincolnshire. At the age of 15 he was placed as a pupil with Mr. John Wilson, a civil engineer in Westminster; but recognizing, even at that age, the need of thorough grounding in the profession he wished to follow, he left very soon and went to Glasgow, where he entered the firm of Messrs. D. Cook & Co. as an apprentice; afterwards he worked in the Caledonian Railway shops as well as on surveying. In 1859 he was employed on the London, Chatham and Dover Railway as an Assistant Engineer under Mr. Mills. After more than eight years of railway work in England, at the age of 23, he was successful in an open competition held in London in May, 1862, for an appointment as an Assistant Engineer in the Indian Public Works Department. He joined the service in India in December, 1862, and was posted to the Central Provinces, then under the Chief Commissionership of the late Sir Richard Temple, and was employed under Mr. J. S. Heyman on the construction of the Great Deccan Road, which formed part of the main line of communication between Calcutta and Bombay. While thus employed Horace Bell received several steps in promotion, becoming Fourth Grade Executive Engineer in April, 1866, Third Grade Executive Engineer in September, 1867, and Second Grade Executive Engineer in March, 1869.

His services during this period received frequent recognition and commendation in the Central Provinces Annual Administration Reports. In January, 1870, he was sent on Railway survey work to the Wardha Valley, and was enlisted in the new State Railway Service initiated by Lord Mayo's Government in May, 1870, and posted to the Indore State Railway, receiving promotion to First Grade Executive Engineer in March, 1871. In April, 1873, he went home on furlough, returning to India in December, 1874, when, after a short term of service on the Punjab Northern State Railway, then under construction, he was transferred in July, 1875, to the Rajputana Malwa Railway, then to the Sindia State Railway, and subsequently to the Rutlam Neemuch Nusserabad Railway, and it is with those lines that his name will be long and honourably identified.

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He was appointed Superintendent of Way and Works of the Rajputana line in August, 1875, and officiated as Manager in addition to the other duties in May, 1876. While thus employed he was promoted to Third Class Superintending Engineer in May, 1877, and to the Second Class in June, 1880. Once more taking leave to England in July 1880, during which time he had charge of the students on the practical course at the Royal Indian Engineering College at Coopers Hill, he returned to duty in November, 1881, and was appointed Engineer-in-Chief of the Dacca Mymensingh State Railway, and early in 1884, was transferred to the Tirhoot State Railway, first as Engineer-in-Chief, and then as both Manager and Engineer-in-Chief. With the exception of a short interval from July to October, 1881, when he officiated as Director of the North Western State Railway, Horace Bell was employed on the Tirhoot State Railway until March 1888, and received the thanks of the Government of India for his services in connection with the construction of the Gunduck Bridge on that line in 1887. He then took six months' leave to England, and on his return was appointed Engineer-in-Chief of the Great Western of India Railway Survey, and in February, 1889, was posted in a similar capacity to the Moghal Serai Railway Survey.

In August, 1890, he was appointed Consulting Engineer for Railways, Calcutta. While holding these various appointments he received promotion to Third Class Chief Engineer in November, 1889, Second Class in June, 1891, and First Class in January, 1892. After a further four months' leave to England in May, 1892, Horace Bell returned for a final term of service, as Consulting Engineer for State Railways to the Government of India, which office he held till his retirement in June, 1894. During that period he also acted for a short time as Director General of Railways in India.

This rapid promotion to one of the highest posts in the Public Works Department was an acknowledgment of his technical ability and high administrative capacity. His talents as a writer were great; he was the author of "Laws of Wealth," a work on political economy, and also of a "Primer on the Government of India," both written for natives of India, and his "Railway Policy in India" has long been recognised as a standard work on that subject. A fluent French scholar and a frequent speaker on Indian railway work, it was natural that his interest in India should not cease with his career in the service of Government. He therefore commenced practice, on leaving India, as Consulting Engineer in London, and, among other works, the Nilgiri Hill metre-gauge

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rack railway and the Southern Punjab 5-feet-6-inches-gauge Railway were constructed under his guidance.

His varied talents and sterling qualities endeared him to his many friends, and his bodily activity seemed to promise a long life after his arduous work in India, but an attack of influenza in the autumn of 1902 developed heart disease, and he died on the 10th April, 1903.

Horace Bell was elected an Associate of the Institution on the 5th March, 1867, and was transferred to the class of Members on the 30th January, 1872. In 1897 he was elected a Member of the Council, on which he served till his death.

JOHN CHAMPNEY BOTHAMS, born on the 25th January, 1822, at Upton, Bucks, was educated at University College School, London, and was subsequently articled to Mr. Henry Austin, under whom he was engaged on the construction of the London and Blackwall Railway. Residing with his master, he frequently met Charles Dickens, a sister of whom Mr. Austin had married. On the conclusion of his articles he was employed from 1844 to 1846 in preparing surveys, plans and sections for various lines of railway, and in 1849 he entered the service of the Metropolitan Commissioners of Sewers. He acted as Resident Engineer on the construction of the Amsterdam Waterworks in 1852 to 1853, and from 1853 to 1855 in a similar capacity on the Salisbury Water and Sewerage Works.

On the completion of the latter works in 1855, Mr. Bothams was appointed Surveyor to the City of Salisbury, which post he held until his death. In that capacity he carried out, in 1884, sewage-disposal works at a cost of £10,000, the process being precipitation by lime, and a new main sewer of concrete to the lower part of the city, to exclude subsoil water. In his private capacity he designed works for the Fisherton Water Company to supply a suburban district. For the last fifteen years the greater part of his duties was discharged by his son, Mr. A. C. Bothams. He died at his residence in Churchfields, Salisbury, on the 14th March, 1903, at the age of 81.

Mr. Bothams was elected a Member of the Institution on the 3rd February, 1880.

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ALEXANDER BREBNER, born in Edinburgh on the 24th December, 1853, was the eldest son of the late Mr. Alan Brebner, M. Inst. C.E. He was educated at the Royal High School, Edinburgh, showing some proficiency in architectural drawing before he left it at the age of 14. He spent the summers of 1867 to 1870 as a mason in dressing stones for Dhu Heartach Lighthouse and in fixing them in their places on the rock. During the intervening winters he attended engineering and science classes and laboratories at the University of Edinburgh. For some time at Earraid Island, where the stones for Dhu Heartach Lighthouse were prepared, he had as companion the late Robert Louis Stevenson, who has referred briefly to the circumstance in one of his books.[1] Mr. Brebner also has left an unpublished fragment bearing on this and other meetings with the celebrated novelist. From 1871 to 1874 he made acquaintance with engineering office work under Messrs. J. and A. Leslie, of Edinburgh, chiefly in connection with waterworks. He was thereafter appointed to superintend the execution of waterworks for Dunbar and for Peterhead. In 1875–76 he was employed under Mr. Thomas E. Harrison, Past-President, at the head offices of the North Eastern Railway Company in connection with designs of jetties and wharves for the Tyne and the Hartlepool Docks. From 1876 to 1880 he was engaged for Mr. (now Sir) John Jackson on the construction of the Queen's Dock, Glasgow, and during that period he also superintended, for Mr. Jackson, the execution of a fishing harbour, comprising concrete piers and excavation. On the completion of the important work of the Queen's Dock, he entered, in 1881, the employment of Messrs. D. and T. Stevenson, of Edinburgh, in which firm his father was a partner. He remained with Messrs. Stevenson for nine years, during which he made himself generally useful, in the preparation of designs for works for the improvement of rivers and estuaries, harbour works of various classes and lighthouse works, acting as Resident Engineer on works carried out by contract, or as Executive Engineer on works carried out without a contractor.

In 1889 Mr. Brebner was selected by the late Sir James Brunlees, Past-President, and Mr. McKerrow to take charge of surveys of the Harbour of Rio de Janeiro, and to report on the best method of carrying out a scheme of docks and warehouses for the improvement of the port, together with railway connections. From

[1] "Memories and Portraits," 1887, p. 130.

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1892 till 1895 he practised on his own account in Edinburgh. He always had a strong literary bent, and during slack periods about this time he wrote "A Little History of China and a Chinese Story," which was published by Fisher Unwin in 1895.

At the end of 1895 Mr. Brebner was appointed Director of Public Works in the Crown Colony of Lagos. But after a few months' duty there he was compelled by an attack of malarial fever to return home on leave in May, 1896. In the following year he was instructed by Messrs. Coode, Son and Matthews to carry out, under Mr. Heenan, Engineer-in-Chief to the Port Elizabeth Harbour Board, an important and intricate marine engineering survey of Algoa Bay. In this task he seems to have been in his element and to have enjoyed the work. He would refer gleefully to the little incident of the boat he was taking soundings from capsizing and his small party being none the worse for the ducking. In his report on this survey he gave an account of sand travel on sea coasts under and on the fringe of tidal waters, which he held to be in some respects novel. Whilst on this Cape work he obtained leave of absence in order to visit the site of the Wonderfontein scheme of water-supply for Johannesburg and a few smaller neighbouring communities, and to report professionally upon it. After going carefully over the ground he reported in favour of the scheme already approved by a Government Commission, suggesting only a modified estimate. This work he did on behalf of a London company. By midsummer of 1899 he had completed satisfactorily the marine survey of Algoa Bay and returned to London. Mr. Brebner died suddenly at his residence in Edinburgh, on the 15th April, 1903. He was a careful, methodical worker, and, though strict, always just in his dealings with those under him, by whom he was greatly respected.

He was elected a Member of the Institution on the 3rd February, 1891.

JOHN CHAMBERS, eldest son of the late Mr. Thomas Chambers, of Aberfoyle, Londonderry, began his engineering career as a pupil of the late Mr. J. Pitt Kennedy. He was employed from 1862 to 1865 on the contract for the Tewkesbury and Malvern Railway, and from 1865 to 1867 on the St. Pancras contract of the Midland Railway. In October, 1867, he was appointed an Assistant Engineer on the Bombay, Baroda and Central India Railway, and in 1870–71 he acted as Resident on the Kattiawar extension

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of that line. In 1871–72 he was employed on the Great Indian Peninsula Railway, and, returning to England, he acted as agent for Messrs. T. and C. Walker, on the construction of the East London Railway in 1873–74. He was next engaged for two years on the staff of the late Sir John (then Mr.) Fowler, Past-President, in the Soudan and Darfour surveys for the Khedive of Egypt, and in June, 1879, he was appointed a Resident Engineer on the Imperial Japanese Railways, of the Tokio-Yokohama section of which system he was placed in charge in June, 1881.

Early in the year 1887, Mr. Chambers entered the service of the Chinese Imperial Maritime Customs, and during the absence on furlough of Mr. D. Marr Henderson in 1888–89 he was appointed Acting Engineer-in-Chief to the Customs. In 1889 he retired from that service and started practice in Shanghai as an Engineer and Architect. Mr. Chambers and the late Mr. Cory designed jointly the new Custom House at Shanghai, and the former subsequently superintended its erection. He died at Shanghai on the 20th February, 1903.

Mr. Chambers was elected a Member of the Institution on the 9th January, 1883.

JAMES GREGSON CHAPMAN, eldest son of the late James Chapman, Commander R.N., died at his residence, 11 Elm Park Gardens, S.W., on the 20th October, 1902, in his seventy-first year. He began his engineering training in 1848, under Mr. Thomas Hunt, at the locomotive shops of the London and North Western Railway at Preston. In 1850 he served under Mr. Joseph Clayton at the Soho Foundry, Preston, and from 1851 to 1855 he was employed under the late Mr. Robert Berthon, Preston. In 1856 he proceeded to Cuba to superintend the erection of land-engines, sugar machinery, &c., for Messrs. Fawcett, Preston & Co., of Liverpool, under contract for three years. In 1859 he established himself in business as a Consulting Engineer in Havana; and during the next ten years he designed and erected colonial machinery of all descriptions, large iron warehouses and railway sheds, steam-ploughing and steam-traction engines, boilers, &c. From 1869 to 1872, in association with his brother, Mr. Alfred Chapman, he designed and carried out two large sugar factories for the Khedive of Egypt, the contractors being Messrs. John Fowler & Co., of Leeds, and Messrs. Fawcett, Preston & Co.; and

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he also designed similar works for Peru, Brazil and other countries. In 1872 he became a partner in the firm of Messrs. Fawcett, Preston & Co., engaged in the design and manufacture of marine-engines, sugar machinery, and hydraulic and cotton-pressing machinery. He remained a partner and director of that firm until his death, but did not take latterly an active share in the business.

Mr. Chapman was elected an Associate of the Institution on the 2nd March, 1875, and was transferred to the class of Members on the 15th January, 1878.

ALFRED CHRISTIAN DOWNEY, who died at Middlesbrough on the 19th April, 1903, served his engineering apprenticeship with Messrs. Fawcett, Preston & Co., of Liverpool. He went from their works, in 1852, to Messrs. Cochrane & Co.'s Ironworks at Dudley, where he remained four years. At their request, in 1856 he transferred his services to Messrs. Cochrane, Grove & Co., of the Ormesby Ironworks, Middlesbrough, as Engineer.

Mr. Downey remained at the Ormesby Ironworks until 1872, when he joined Mr. Carl Bolckow and erected the Coatham Ironworks near Redcar, which were carried on under the style of Downey & Co., Mr. Downey being the managing partner. The firm afterwards took over the Lackenby Ironworks near Middlesbrough, which were reconstructed and managed by Mr. Downey for several years. In connection with the latter works the firm bought the Stanghow Ironstone Mines at Boosbeck from the Trustees of the late Mr. George Wythes. These mines were opened and remodelled under Mr. Downey's management—the ironstone produced being smelted at the Lackenby Furnaces.

From 1892 to the date of his death Mr. Downey was engaged in managing the Engineering Works of Messrs. John Turner & Co. at Middlesbrough, and also as Consulting Engineer in connection with blast furnace operations in the Middlesbrough district. Mr. Downey was always a friend of his workmen, and a persistent advocate of conciliation, not only in his own business, but as a member of the Ironmasters' Association. He was one of the early members of the Iron and Steel Institute.

Mr. Downey was elected a Member of the Institution on the 1st May, 1883.

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CHARLES FARQUHAR FINDLAY, third son of the late Rev. James Findlay, was born on the 18th June, 1853, at Lerwick. He graduated at Cambridge in 1876 as tenth Wrangler in the Mathematical Tripos, was made a Fellow of his College, Trinity Hall, and appointed a Mathematical Tutor. Becoming desirous, however, of a more active profession than a college life promised, he articled himself in 1877 to the late Mr. G. F. Lyster, Engineer to the Mersey Docks and Harbour Board, with a view of entering the engineering profession, for which he had a natural aptitude, in addition to his special mathematical attainments. In March, 1880, he was appointed an Assistant on Mr. Lyster's Staff, when he introduced the lattice-girder pattern of swing-bridge at the new docks then being made at the south end of Liverpool; and in November of the following year he resigned that post, with the idea of completing his education by a tour round the world. He spent some time in engineering work in both North and South America, was engaged in tramway construction in Chicago, invented some improvements in cable tramways, and was employed on bridge-building in Peru.

In 1884 Mr. Findlay joined the staff of Sir Alexander Rendel as a Chief Inspector of bridge-work, the Sukkur Bridge being the most important of the works which came under his supervision at this period. After occupying that post for some years he set up in practice for himself. In 1895 he was offered the appointment of District Engineer by the Board of the East Indian Railway Company, and thereafter became Deputy Chief Engineer and, eventually, Chief Engineer in March, 1903. His untimely death from cholera on the 15th May, 1903, at Calcutta, deprived the Company of a most able engineer. Mr. Findlay left a large circle of friends, both in and out of the profession, by whom his memory will always be cherished, for none who knew him well could fail to be struck with his absolute straightforwardness and his singular modesty.

Mr. Findlay was elected an Associate Member of the Institution on the 1st February, 1881, and was transferred to the class of Members on the 12th March, 1899. In 1900, he contributed to the Proceedings a Paper entitled "Note on the Floor System of Girder Bridges,"[1] which was discussed in conjunction with Mr. W. B. Farr's Paper "Moving Loads on Railway Underbridges."

[1] Minutes of Proceedings Inst. C.E., vol. cxli. p. 17.

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JAMES HENDERSON, born in Aberdeen in 1821, a descendant of Hendersons of Hallyards, Perthshire, was the son of the late Lieutenant-Colonel George Henderson, Royal Engineers. His father, as well as his uncle, Admiral Robert Henderson, served with distinction, the former under Wellington, the latter under Nelson. The subject of this notice began his professional career at an early age as a pupil under the late Mr. Edward Dixon, Resident Engineer on the London division of the London and South Western Railway. In 1839 he became himself Resident Engineer on a portion of the line, under the direction of Mr. Joseph Locke, Past-President. Later in that year he proceeded with a party of Royal Engineers under Captain (subsequently General) E. C. Frome, to South Australia, where he was engaged in extensive surveys, notably of Lake Alexandrina and the north-west bend of the River Murray, in the course of which he endured considerable hardship and privation. In 1841 he was transferred to the Department of Public Works, and ten years later, on the death of his elder brother, he returned to England with his wife and two sons. He had in the meantime married a daughter of the late Mr. C. B. Newenham, High Sheriff of South Australia.

His father's large interest in Cornish mines induced Mr. Henderson to settle in Truro as a Mining Engineer and Surveyor. Fresh from the healthy surroundings of his life in Australia, he brought to his new work a fund of vigour and vitality which carried him through the dangers and discomforts of the early mining days, when Government Mine Inspectors were unknown and little or no care was paid to the preservation of life or limb. With a powerful physique and robust health, Mr. Henderson carried on his arduous life beyond the usual limits. Seventy years and more still found him as keen as ever, going through a long day's work underground, climbing ladders and breathing vitiated air with impunity. In the evening he would be found working out his trigonometrical observations, and the next day plotting and draughting his work, with hand and eye as steady as in the early Australian days.

In November, 1902, Mr. Henderson was honoured by the City Council of Truro (though not a member of the Council himself) with the invitation to accept the office of Mayor, in view of the approaching dedication of the nave of the cathedral, and entered on his new and unaccustomed duties with energy and vigour. He died at his residence, Dalvenie, Truro, on the 13th April, 1903, in his eighty-second year.

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At the International Exhibition of 1862 Mr. Henderson was awarded a bronze medal for mining plans. In 1868 he received the bronze medal of the Royal Cornwall Polytechnic Society for a plan of the Botallack Mine, and a silver medal in 1869 for an improved dial, while in later years he was the inventor of the surveying instrument known as "Henderson's rapid traverser," which is much used in the dense forests of West Africa. As a Captain of Volunteers, he devoted himself with great energy to military duties, and was well known as a marksman. He organised the Truro Volunteer Fire Brigade, and commanded it for twelve years.

Mr. Henderson was elected an Associate of the Institution on the 6th February, 1855, and was transferred to the class of Members on the 27th November, 1877. In 1858 he was awarded a Telford Medal for a Paper on "The methods generally adopted in Cornwall in Dressing Tin and Copper Ores."[1]

WILLIAM BOURNE LEWIS, second son of Mr. Alderman Lewis, J.P., of Worcester, was born in that city on the 13th January, 1831, and was educated at home and at private schools. He was articled in 1848 to his father's friend, the late Mr. Richard Varden, who, under Brunel, was engineer for the Oxford, Worcester and Wolverhampton Railway. He was afforded rare advantages in his pupilage, as the plans for some 93 miles of railway, through a somewhat difficult country, were prepared in Mr. Varden's office from designs supplied by Brunel. He was stationed for nearly twelve months at the Mickleton Tunnel and acquired early a practical knowledge of materials and methods of construction. Under Mr. Varden's advice, he accepted a post in Brunel's office under Mr. Fisher, who had charge of the preparation of the specifications of works for which Brunel was responsible, from which he obtained most useful information.

Amongst the various subjects for which, under Brunel's instructions, Mr. Lewis had to draw up specifications, may be mentioned the Crystal Palace water-towers, the locomotive power on the South Devon Railway, the Saltash bridge, a timber slipway for launching the "Great Eastern," the South Wales Railway, the

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[1] Minutes of Proceedings Inst. C.E., vol. xvii. p. 195.

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Vale of Neath Railway, the Wilts, Somerset and Weymouth Railway, the Cornwall Railway and West Cornwall extensions, and one that ultimately had an important influence on Mr. Lewis' career, the Eastern Bengal Railway, which was eventually let to Messrs. Brassey, Paxton and Wythes. This work brought him into intimate connection with Mr. Wellington Purdon (afterwards his partner) and Mr. Brassey.

Meanwhile Brunel's extraordinary energy and devotion to work told upon his health, and Mr. Lewis was employed to convey to the several Resident Engineers and others the instructions of the Chief. This greatly enlarged his knowledge and experience, while it filled his hands with work at a time when he enjoyed good health and unflagging energy.

In addition to the Eastern Bengal Railway, other foreign and colonial work passed through the office. The Adelaide City and Port Railway involved the purchase and shipment of considerable plant, with which Mr. Lewis had much to do. And when Brunel was appointed Engineer to the Railway Department of the Government of Victoria, he placed Mr. Lewis in charge of the arrangements for the inspection of the materials. This grew into a very large business, which was carried on by Mr. Lewis for many years, first in connection with Brunel's successor, the late Mr. R. P. Brereton, and finally on his own account as Consulting Engineer to the Victorian Government.

After Brunel's death in 1859, Mr. Lewis determined to start in the profession on his own account, and he and his friend, the late Mr. William Jacomb, took offices together (but not as partners) in Westminster.

On Brunel's death his successor, Mr. Brereton, and Mr. Lewis continued the Victorian work until the troubles of 1893–94 arose, when the Colony ceased to employ an engineer in England. In the earlier days much interesting work was involved. Over £3,000,000 was spent in the purchase of plant and machinery. Complete designs were furnished by Mr. Brereton and Mr. Lewis for the caissons and the pumping and other machinery of the Alfred Graving Dock at Melbourne, also drawings for the large workshops for the railway system of Victoria.

Mr. Lewis' connection with Mr. Brassey began with the Eastern Bengal Railway and was continued in the construction of the Calcutta Waterworks carried out by Messrs. Brassey, Wythes and Aird. Mr. Lewis, who had done much to induce these three gentlemen to take up the scheme as partners, acted for them in London throughout the whole of the work, and a few years later he was engaged

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in a similar capacity for the Simla Waterworks carried out by Messrs. John Aird and Sons.

Mr. Wellington Purdon, on his return from India after the completion of the Eastern Bengal Railway, became interested in several Irish railway schemes, and Mr. Lewis joined him as partner in these works, an arrangement which lasted over fifteen years, until Mr. Purdon's retirement from business in 1880. Among the works carried out by Messrs. Purdon and Lewis may be mentioned the Fermoy and Lismore Railway for the Duke of Devonshire, the Waterford, Dungarvan and Lismore Railway, and Rosslare Harbour Works (not completed).

While the Irish work was in progress Mr. Lewis became Engineer for the construction of the Worcester, Bromyard and Leominster Railway, a line chiefly promoted by some old friends of his father. The line was opened between Worcester and Bromyard in 1878, and taken over by the Great Western Railway Company as part of their system.

In 1881 Mr. Lewis assisted the late Mr. W. H. Barlow, Past-President of the Institution, in preparing for Parliament a scheme known as the Regent's Canal City and Dock Railway. Mr. Lewis threw himself into this work with great energy, the Bill passed both Houses of Parliament, but financial troubles ensued, and the powers lapsed.

In 1882 Mr. Lewis was called in by the trustees of the late Lord De La Warr to advise as to the best means of protecting the Earl's property at Bexhill from the inroads of the sea. This began an intimate connection between Mr. Lewis and Bexhill which lasted until his death. The successful protection of the estate by means of groynes and a sea-wall was followed by the development of the place as a health resort. A gas and water company was formed, Mr. Lewis carrying out the waterworks, while Mr. Corbet Woodall was responsible for the gasworks.

On the 12th February, 1885, Mr. Lewis was summoned to advise the Government as to the selection of contractors for constructing the Suakin and Berber Railway. During the short time that the line was in progress, and in the settlement following the Government's decision to abandon the project, Mr. Lewis acted as intermediary between Messrs. Lucas and Aird, the contractors, and the War Office.

In his early manhood the strain of incessant work through many years with little or no holiday told heavily on Mr. Lewis' naturally delicate constitution, and between the ages of 38 and 48 his health was much shattered. He suffered greatly from sciatica

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and rheumatism, and had to relinquish a great deal of business. Happily, he largely recovered his health, although always remaining delicate, and was able to lead an active and busy life until his retirement from business in 1895, after which, however, he still continued his Bexhill work. To the end he manifested a keen interest in all that was going on in the engineering world. He had a large circle of friends in the profession, and few men were more respected. His sterling uprightness, coupled with his genial manner and ready sympathy, formed a striking personality which was framed in a correspondingly handsome physique. He died at Blackheath, where he had resided for over fifty years, on the 24th December, 1902, within three weeks of his 72nd birthday.

He was elected a Member of the Institution on the 6th February, 1866, and until latterly, was a regular attendant at its meetings. He took special interest in the Benevolent Fund, and served several times on the Committee of Management.

THOMAS MONRO, born in Ireland on the 27th November, 1831, began his engineering career in 1851 in Canada, where he was employed under Mr. T. C. Keefer on surveys for the Montreal and Kingston Railway, the St. Lawrence (now the Victoria) Bridge at Montreal, and the Montreal Waterworks. From 1853 to 1856 he had charge of a portion of the Grand Trunk Railway construction at Prescott, and from 1857 to 1859 he was employed on the Hamilton Waterworks, and as Assistant Engineer on the preliminary work of the Hamilton and Port Dover Railway.

In 1860 Mr. Monro entered the service of the Canadian Government, in which he remained until his death. During that period of forty-two years he occupied various important positions. In 1863 he was appointed one of the Government Inspectors of Railways, and in the following year he was specially sent to report on the best means of supplying water to the Parliament Buildings at Ottawa. In 1868–69 he examined the east shore of Lake Huron and the north shore of Lake Erie, with a view to the establishment of harbours of refuge on those lakes, and in the autumn of the latter year he made a part examination of the east end of the "Dawson" route as a proposed means of water communication with the north-west. In 1870–71 he located the

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new Welland Canal, and in 1872 he was appointed Engineer in charge of all the enlargement works. The work was, however, afterwards subdivided, and Mr. Monro continued in charge of the construction of the new line from Allanburg to Port Dalhousie, on which all the new locks are situated, and retained that post until the end of 1888, the canal having been ultimately enlarged to a draught of 14 feet. In 1889 he was specially sent by the late Mr. John Page to report on the best location for a 14-foot canal between Lakes St. Louis and St. Francis. After much opposition this was placed, as surveyed by him, on the north side of the St. Lawrence, and was completed under his superintendence a few months before his death. It was named by him the "Soulanges Canal." Several important changes were made in the plans of the locks, etc., in order to facilitate the passage of vessels and at the same time reduce the cost of the works.

Mr. Monro also designed the waterworks for the city of St. Catharine, and for Merriton, on the Welland Canal, and reported on systems for other places. In 1891 he was sent by the Canadian Government to examine and report on the Manchester Ship Canal. He also acted as Chairman of a Board of Engineers in 1895 to enquire into matters connected with the harbour of Montreal, and in the autumn of that year represented the Government at the annual convention of the Deep Water-ways Association, held at Cleveland, U.S.A. In November, 1895, he was made a member of the Commission appointed by the Canadian Government to confer with that named by the President of the United States, to report on the best line for a deep water-way to connect the Great Lakes with the Atlantic Ocean. Mr. Monro had very extended experience in dealing with matters connected with hydraulic engineering. He married, in 1860, Ellen Jane, second daughter of the late Rev. Dr. Strong, formerly Rector of Christ Church, Ottawa. Mr. Monro died at Coteau du Lac, in the Province of Quebec, on the 19th March, 1903.

He was elected a Member of the Institution on the 12th January, 1886.

JOHN PRICE, born on the 16th August, 1833, served his apprenticeship as an Engineer, first with the late Mr. James Keen, and subsequently with Mr. George Clark, both Mechanical Engineers, of Sunderland. In August, 1855, he was appointed

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Second Engineer to H.M. Floating Factory "Chasseur" under the late Mr. R. S. Fraser, and, in the following month, the duties of Secretary to the Floating Factory were also entrusted to him. He held those posts until September, 1856, when the vessel finished its work at Balaclava and was put out of commission.

Mr. Price joined the firm of Pile, Spence and Co., steamship builders, of West Hartlepool, in the year 1858, and remained in their employment until August, 1863, during which time, in addition to being Engineer to that firm, he held the post of Superintending Engineer to the West Hartlepool Steam Navigation Company. In September, 1863, he was appointed Chief Surveyor to the Underwriters' Registry for iron vessels, which post he held until March, 1876. During that period he contributed materially to the settlement of a basis on which the scantlings of iron ships were fixed, and he presented two Papers on that subject to the Scottish Shipbuilders' Association.

In March, 1876, Mr. Price was appointed General Manager to the Palmer Shipbuilding and Iron Company, of Jarrow-on-Tyne, a post which he held until 1894. During that period great changes were made in the works of the Company under his supervision. The blast furnace department was largely extended, a complete steel-melting plant on the Siemens-Martin principle and an extensive bar mill were laid down, and the plate mills were also completely re-arranged and extended. The shipbuilding and engineering departments were also brought up to date and fitted with modern appliances, and such vessels as the "Orlando" and "Undaunted," the "Pique," "Rainbow" and "Retribution," and the "Resolution" and "Revenge," all built for H.M. Navy, were constructed under his management. During his career at Jarrow the tonnage of the vessels launched amounted to about 650,000 tons, and in the year 1889 the tonnage launched amounted to 64,669 tons.

In 1895 the firm of C. S. Swan and Hunter, of Wallsend-on-Tyne, was converted into a private Limited Liability Company, and Mr. Price joined the Board of Directors and maintained an active connection with the Company to the time of his death, which took place at his residence in Newcastle-on-Tyne on the 27th January, 1903.

Mr. Price took an active part in the municipal life of Jarrow during the period of his connection with the Palmer Shipbuilding Company, and was also associated for many years with the 1st Durham Engineer Volunteers, of which corps he was Colonel.

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He was twice Mayor of Jarrow, a Magistrate for the borough, and a Member of the River Tyne Commission.

Mr. Price was elected a Member of the Institution on the 5th December, 1882.

HENRY WEDGWOOD RENDEL, fifth son of Sir Alexander Rendel, was born on the 4th November, 1866, and received his professional training at the Royal Naval College, Greenwich, at Messrs. Neilson's Locomotive Works, Glasgow, and at the Elswick Works. His first responsible charge was the erection and maintenance for the contract period, in 1893–94, of the machinery for the Government Dockyard at Bombay, which was supplied by the Elswick firm. He then remained with the firm at their Pozzuoli works till 1896, when he joined his father as Inspector, being employed in America as well as in Great Britain. In 1898 he was taken into partnership, but a promising career was cut short by his death on the 30th May, 1903, from an attack of acute laryngitis.

Mr. Rendel was elected an Associate Member of the Institution on the 12th January, 1897, and was transferred to the class of Members on the 20th January, 1903.

JOHN SCOTT, C.B.,[1] the well-known shipbuilder and engineer, died at his residence, Halkshill, Largs, on the 19th May, 1903. He was born on the 5th September, 1830, at Greenock, the eldest son of the late Mr. Charles Cuningham Scott, of Halkshill, Largs, and was educated at Edinburgh Academy and the University of Glasgow, and served a regular apprenticeship as an engineer with his father's firm, where many of the early Clyde ships, both for the naval and mercantile fleet, were built and engined. In his twenty-second year Mr. Scott became a partner in the firm, and in 1868 he took the responsible position of head of the concern, retaining it until the end, in association with his brother, Mr. R. Sinclair Scott.

Being endowed with great progressive spirit, John Scott soon recognised the economy of higher steam pressures, and designed a

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[1] This notice has been abridged from *Engineering*, 22nd May, 1903, by permission of the Editors.

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two-cylinder engine to utilize a pressure of 125 lbs., and showed his confidence in its practicability by himself ordering about 1857 the construction of a steamer of about 650 tons, the "Thetis," in which to experimentally test the problems associated with such an advance. The boiler used was of the Rowan type, with water tubes, the total power obtainable being 300 HP. The engine proved satisfactory and only consumed 1·018 lbs. per I.HP. per hour; but because of internal corrosion in the tubes, owing to chemical action, it was found necessary to withdraw the boilers after eighteen months' service.

Mr. Scott proved his continued confidence in higher steam pressures by building a second set of machinery to work at 140 lbs., and, moreover, introduced the water-tube boiler into a corvette which he built for the French Navy. This vessel, completed in the early sixties, was the first in the French Navy to be fitted with compound engines. This application of the water-tube boiler and compounding system was the result of a proposal made by Mr. Scott to Mr. Dupuy de Lôme, who was then head of the department. Mr. Scott was at the same time building engines for four small corvettes, under construction at the Woolwich and Deptford yards for the British Navy, and the Admiralty agreed to have fitted in one of them water-tube boilers and engines similar to those built for the French boat. This boiler may be said to have belonged to the same general type as the Thornycroft and Normand boilers. It was subsequently found impossible to ensure that the top of the boilers would be at least 1 foot under the load-line, a condition then enforced in steam vessels for the Navy, and the adoption of the water-tube boiler was deferred.

Mr. Scott, however, continued to work for the successful application of high pressures, and it was this that brought him into contact with Mr. Samson Fox, with whom he was closely identified for many years in connection with the development of the corrugated flue. For many years subsequent to 1878 Mr. Scott was Chairman of the Leeds Forge Company, and he was associated with Mr. Fox in carrying out the first really effective series of trials with circular furnaces to determine their strength. He also conducted at Greenock interesting tests with boilers which had been manufactured for the gunboats "Sparrow" and "Thrush," built by his firm for the British Navy. It was on this subject that Mr. Scott contributed in 1889 his only Paper to the Institution of Naval Architects.[1]

[1] Transactions Institution of Naval Architects, vol. xxx. p. 287.

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The subject of this notice was closely identified with the successive stages in the development of the marine engine. He built some of the largest side-wheel engines made in the early years of steamships, ranging up to 3,500 tons, and in 1865 the first vessels of the Ocean Steamship Company which performed the voyage to Shanghai round the Cape of Good Hope in 65 days, including calls on the China coast, the consumption of fuel being at the rate of about 2¼ lbs. per I.HP., averaging about 20 tons per day. Mr. Scott's firm also built several of the Holt engines, and engined some of the later ships of the British fleet, including the battleships "Canopus" and "Prince of Wales," and at the present time they have in course of construction a 10,700-ton cruiser—the "Argyll"—which, with 21,000 HP., is to attain a speed of 22½ knots. It may be mentioned that the firm were the first to build a warship on the Clyde—a sloop-of-war, the "Prince of Wales," constructed exactly one hundred years ago. A few years later came the steam frigate "Greenock," which was one of the first iron ships built for the British Navy. For the Eastern trade the firm have latterly built many notable ships.

Mr. Scott took great interest in politics, and on three occasions stood, unsuccessfully, as Conservative candidate for Greenock. He acted for many years as Deputy Chairman of the Harbour Trust of Greenock, and for 25 years as Chairman of the local Marine Board. Mr. Scott was a great lover of books, and the library he formed with skill and scholarly taste was one of the best private collections in Scotland. He was one of the original Members of the Institution of Naval Architects, of which he was elected a Vice-President in 1903, a Member of the Institution of Engineers and Shipbuilders in Scotland, a Fellow of the Society of Antiquaries, and a Fellow of the Royal Society of Edinburgh. In early years he found his principal enthusiasm, outside of engineering, in the Volunteer movement, and in 1859 he raised two batteries of artillery volunteers; from 1862 he was Lieut.-Colonel of the Renfrew and Dumbarton Artillery Brigades, and although he relinquished active duty in 1894, he continued to be Honorary Colonel. For his services in this connection he was created a Companion of the Bath in 1887. Yachting was, especially in later years, his favourite pastime. He was a member of most of the Scotch yachting clubs, and for many years Commodore of the Royal Clyde Yacht Club. He advanced the municipal, educational, and social interests of his native place; but after all, his business absorbed the greater part of his enthusiasm, and he

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continued in harness almost to the end, although for some weeks he had begun to feel the infirmities of his 73 years.

Mr. Scott was elected a Member of the Institution on the 6th March, 1888.

THOMAS ROBERT SHERVINTON began his engineering career in the service of the Board of Works in Ireland, and was employed on the famine relief works of 1846–48. From 1849 to 1854 he was engaged under Mr. Peter Barlow as Assistant and Resident Engineer in charge of works chiefly on the South Eastern Railway. On the recommendation of Mr. Barlow he was appointed in 1854 an Assistant Engineer in the service of the East Indian Railway Company. Two years later he was promoted to be Resident Engineer, and in that capacity, and subsequently as a District Engineer, he had charge of works of great magnitude and considerable engineering difficulty. During the mutiny he served as a Volunteer in a Rifle Corps.

On the completion of the extensive works on the East Indian Railway, Mr. Shervinton was offered an appointment in Japan, that country having determined to establish railway communication from the coast to the capital, a system which, including Government and private lines, has now extended to over 4,000 miles. He ultimately became the Chief Engineer to the whole system of railway communication in Japan, his clear, concise and systematic conduct having won the confidence of the Japanese in a remarkable manner. His offer to introduce a system of engineering instruction for the youth of Japan was eagerly taken advantage of; and great progress in that respect was made under his direction. Reference should be made to the extent and magnitude of the works carried out by Mr. Shervinton, in spite of great difficulties in a country subject to frequent volcanic action. The success of the first tunnel at Otsu was a virtual triumph to the Japanese, and the difficulty thenceforth was to induce them to consent to a line which would not have a tunnel on its route.

After seventeen years' service in India and eight years in Japan, Mr. Shervinton desired to be relieved from the unceasing cares and responsibilities of his arduous post. The Japanese, unwilling to part with an adviser in whom they placed absolute confidence, made him most liberal offers if he would remain, but, finding that he adhered to his determination, the Japanese Government

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appointed him their Consulting Engineer in England, submitting for his personal consideration all new railway projects, and entrusting him with the provision of the material and equipment of the same. So entirely suited to the exigencies of the country were his designs for locomotives that, with the permission of the Government, they have been adopted throughout Japan in the railways built by private enterprise. The Japanese Government signalized their high appreciation of his services by conferring on him the Imperial orders of "The Rising Sun" and "The Sacred Treasure." He died at his residence, 14 Earl's Court Square, London, on the 30th April, 1903, aged 76.

Mr. Shervinton was elected a Member of the Institution on the 2nd April, 1867.

WILLIAM HARRY STANGER, born on the 24th September, 1847, at Pietermaritzburg in Natal, was the son of the Hon. William Stanger, M.D., who had been with the Niger expedition of 1840 as naturalist, and in 1845 became Surveyor-General of Natal. Dr. Stanger brought his family to England in 1851 and the subject of this notice spent his boyhood in this country, receiving his education at the Grammar School at Norwich and at King's College, London. Mr. Stanger obtained his early training as an Engineer at the works of the Hunslet Engine Company, Leeds, and afterwards at those of the North Eastern Railway. In 1870 he obtained the post of instructor of traction-engine driving at Woolwich and Aldershot, and, although quite a young man, showed considerable skill in demonstrating the capabilities of the road tractors of that day. Mr. Stanger was next employed in Brazil as Engineer to the Ceará Steam-Traction and Transport Company, which became merged in the Ceará Railway Company, and under that Company he held the post of Locomotive Superintendent during part of 1872. Unfortunately he contracted yellow fever, which undoubtedly left its mark upon him, and may even have contributed to his early death.

On his return to England his father's connection with colonial administration stood him in good stead, and on the recommendation of Sir William Sergeant he was appointed in 1873 Engineering Clerk to the Crown Agents for the Colonies and Inspector of Permanent Way Materials for the Trinidad Government Railway. The post carried with it no great emolument, but it was a stepping-stone to more responsible and remunerative appointments. After

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a short time it was found convenient to separate the two classes of work, and, leaving the Colonial Office, Mr. Stanger established himself in Westminster, acting as Inspecting Engineer for much of the material bought by the Crown Agents on behalf of the Crown Colonies. Eventually he was entrusted with the inspection of such engineering materials as are commonly known as "stores." In order to appraise their quality it was necessary that they should be chemically examined, and Mr. Stanger sought the assistance of a chemist. For this purpose in 1886 he employed as his assistant Mr. Bertram Blount, and undertook the systematic examination of such stores as could be valued analytically. About this time Mr. Stanger, who was fully alive to the importance of chemical as well as mechanical testing, decided to establish a testing works and laboratory, and in 1887 obtained, enlarged and fitted premises in Broadway, Westminster, in which both branches of work could be carried on.

The early years of this enterprise were not without difficulty; testing came slowly, the work of inspection increased only by degrees and the chemical laboratory was not overcrowded. But in this probationary period good, solid, honest work was being done, and practice began to come from outside sources as well as from those that were official. In particular was this true of the chemical and analytical work, begun simply as an adjunct, but so increasing as to demand in 1891 the creation of the firm of Stanger and Blount, by whom it has since been carried on.

Meanwhile, Mr. Stanger's own engineering work continued to increase and his notable talents became more fully recognised. He applied himself to the testing and inspection of cement, and established so high a reputation for thoroughness and skill that in 1895 he was entrusted with the examination of the vast quantities of cement about to be used in the large national harbours provided for by the Admiralty Works Loan. It is satisfactory to know that no serious question has arisen, or is likely to arise, concerning the quality of the cement supplied to these important undertakings during Mr. Stanger's tenure of office; with his excellent system of inspection and careful mechanical tests and with the chemical control exercised by his coadjutor the quality of the material was beyond question, and it is not too much to say that the country, which often knows little of its benefactors, owes gratitude to W. Harry Stanger.

In course of time not only the Crown Agents for the Colonies, who were his first employers, but also numerous self-governing colonies, through their Agents-General and various departments of

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the Admiralty, engaged Mr. Stanger to inspect and test structural materials, machinery and stores of all kinds. In the execution of this he was necessarily brought into close relations with contractors and manufacturers, and it was his duty to ensure that the material supplied was of high quality. In such a position difference of opinion is certain to arise from time to time, and nothing but a happy combination of firmness in essentials and reasonable concession in trivial things can prevent continual conflict. The possession of these qualities rendered Mr. Stanger peculiarly fitted for his post as government inspector, and while serving his official chiefs faithfully and well he remained personally and professionally acceptable to all but the most captious contractors.

In the early nineties the cement trade of this country felt it desirable to investigate the growing practice of adding foreign ingredients to Portland cement. The question was taken up by the Cement Trade Section of the London Chamber of Commerce in 1894, and the matter was fully investigated by Mr. Stanger and his partner, who reported against the practice in terms so definite that the members of the Cement Trade Section bound themselves to abstain from it, and to expel any member who contravened the resolution that cement sold by members of the section should be pure. A considerable triumph for honest trading was thus secured and the legitimate apprehensions of engineers were allayed. The matter attracted much attention at the time, and the results were imbodied in a Paper by Messrs. Stanger and Blount read before the Society of Chemical Industry in 1897. The same Authors contributed various other Papers on subjects connected with cement to the Journal of the Society from time to time, and in November, 1900, they presented to this Institution a Paper on the "Rotatory Process of Cement Manufacture,"[1] which may be described as a complete exposition of this novel method of manufacture, and was awarded a Telford premium.

In character Mr. Stanger presented many admirable qualities. His unswerving probity, loyalty alike to those in whose service he acted and to his co-workers, generosity to his subordinates and staunchness to friends, by themselves constitute a fine record. He was a born director and organiser, was equipped with a sound knowledge of engineering ripened by long experience of the mechanical side of the profession, and was in all things practical. In general affairs he was capable of taking wide views and in judgment was rarely at fault. There was a side of tenderness

[1] Minutes of Proceedings Inst. C.E., vol. cxlv. p. 44.

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and charity in his character which led him quietly and almost with concealment to aid and protect many who appealed to him for help; few but his friends ever knew of these kindly acts. They understood his generosity as fully as the outside world admitted his integrity. He died at his residence, 33 Ladbroke Grove, on the 13th February, 1903, aged 55.

Mr. Stanger was elected an Associate of the Institution on the 3rd February, 1874, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 11th November, 1890.

EDWARD GRAY STRONG, born in Bruges on the 19th June, 1826, received his engineering training in the works of Messrs. Napier at Lambeth. He was subsequently employed on the South Eastern Railway at New Cross, and in the drawing office and works of the London and North Western Railway at Crewe, and from 1853 to 1865 he was in the service of the Caledonian Railway Company, at first as an Assistant Engineer and subsequently as District Locomotive Superintendent. In February, 1865, he was appointed Locomotive Engineer of the Ceylon Government Railway, from which post he retired in January, 1885.

At the time of Mr. Strong's arrival in Ceylon the railway between Colombo and Kandy was still under construction, and the whole line was not completed and opened until August, 1867. Mr. Strong in the meantime was engaged in the supervision and erection of workshop machinery, locomotive, carriage and wagon rolling-stock, and other details necessary in connection with the opening of a new line of railway, the materials for which were imported from England in sailing ships, the Suez Canal not then being opened. The heavy machinery and packages had to be unloaded in an open roadstead and landed and removed without the aid of the appliances now available, a work which entailed no small amount of responsibility and skill.

On the opening of the line to Kandy, Mr. Strong was appointed Resident Engineer, in which capacity he had charge of the engineering as well as the locomotive, carriage and wagon departments. The permanent way and works were maintained under contract for a stipulated period, on the termination of which the line was maintained departmentally. As Resident Engineer, Mr. Strong carried out several important works besides his duties

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on the line, viz., the survey, with plans and estimates, for the extension of the line to Nawalapitiya, 17 miles in the hill country of Kandy. This branch was opened for traffic in December, 1874.

In 1875 an extension of the main line from Colombo southwards, following the sea coast, was projected. The preliminary work was undertaken departmentally, and plans and estimates were prepared for 26 miles to Kalutara South. This extension, which was completed and opened for traffic in September, 1879, brought railway construction in Ceylon to a standstill for some time, and was the last line carried out by Mr. Strong.

New bridges, for double lines of rails, were then constructed over the Kalutara Canal and the Kelaniya River, near Colombo. A number of main-line stations were also replaced by buildings giving more accommodation to meet the requirements of traffic. Many other improvements were carried out by Mr. Strong during his tenure of office, and by his retirement the Ceylon Government lost a most able, zealous and conscientious officer, who had ever their best interests and the welfare of the railway at heart.

He was of a modest and retiring disposition, which prevented his abilities as an engineer from being more generally known, but his many good qualities endeared him to those who had the privilege of his friendship. He was kind and considerate to those who served under him, and he took a deep interest in the welfare of his native staff and dependents, who were much attached to him. He died at Tunbridge Wells on the 23rd April, 1903, in his 77th year.

Mr. Strong was elected a Member of the Institution on the 7th December, 1875.

EDWARD WOODS,[1] who was perhaps the oldest railway engineer in this country, died at his residence, 45 Onslow Gardens, London, on the 14th June, 1903, at the age of 89.

He was born in London on the 28th April, 1814, and received his early education at private schools. When he was 15 he went to Bristol and began definitely to study for his future profession. His various holidays were spent in visiting the great engineering works which were then in progress. In 1834 George Stephenson relinquished the charge of the Liverpool and Manchester Railway

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[1] This notice is reprinted, with some modification and addition, from *Engineering*, 19th June, 1903, by permission of the Editors.

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in order to undertake the construction of the Grand Junction Railway from Warrington to Birmingham. The vacancy thus created was filled by the promotion of Mr. John Dixon from the post of Resident to that of Chief Engineer. At the same time Edward Woods was appointed one of Mr. Dixon's assistants, and took charge of the section from Liverpool to Newton-le-Willows, a length of 15 miles, including the tunnel between Lime Street and Edge Hill, which was then in course of construction. The duties assigned to this young engineer were to superintend the works, to look after the contractors for the permanent way, set out new works, pay the contractors, police, etc., along the line, and attend the fortnightly meetings of the Board of Directors.

In 1836 Mr. Woods succeeded Mr. John Dixon as Chief Engineer to the Liverpool and Manchester Railway, with the additional charge of the mechanical department. It was thus his good fortune to have the opportunity of observing the gradual and progressive development of the railway system from its very early days. One of the first practical experiences he there gained was the importance of laying the rails on an elastic road-bed. In the first instance the line had been laid, during its construction in 1829, with wrought-iron "fish-belly" rails, costing £11 to £12 a ton, carried in chairs which were fixed in stone blocks in all the cuttings, whether in clay or in rock. Sleepers were only used on the embankments, in order to facilitate the repairs of the road and the raising of the line when the embankments settled. How firmly the mistaken belief in a rigid roadway was at first entertained may be gathered from the fact, recorded by Mr. Woods, that, in making the Manchester and Bolton Railway, Mr. Jesse Hartley, then the Engineer to the Liverpool Dock Estate, who had great faith in solid masonry, and to whom the engineering of the line had been entrusted, even went so far as to build solid stone walls for laying the rails on; the whole road had afterwards to be taken up and relaid with sleepers. The removal of the stone blocks from the cuttings on the Liverpool and Manchester line was a less serious undertaking, and some of these curious reminders of the earliest lessons learnt in the construction of permanent way are still to be seen piled alongside certain portions of the railway.

The original tunnel, of 2,025 yards length, rising from Lime Street Station, in Liverpool, up a gradient of 1 in 97 to Edge Hill Station, was worked from the outset until March, 1870, with ropes driven by winding engines at the top of the incline. But Edge Hill being in 1830 a residential suburb, the boilers and chimney were required to be placed about a quarter of a mile

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distant from the engine, to which the steam was conveyed through a cast-iron main of 10-inch bore, along a culvert driven through the red sandstone rock. Here during July, 1836, Mr. Woods made observations which showed that the condensation in the long steam main caused the loss of half the fuel burnt. Besides the tunnel, there were two other inclines on the Liverpool and Manchester Railway, each 1 in 90, which George Stephenson originally contemplated working by fixed engines and ropes; but that intention was abandoned after it had been found that locomotive adhesion was itself sufficient. In subsequently laying out the Lancaster and Carlisle Railway, Joseph Locke did not shrink from a locomotive gradient of 1 in 70 for the Shap Fell incline of 7 miles length. Robert Stephenson, however, limited himself to 1 in 330 for the ruling gradient of the London and Birmingham Railway. The cost of working the three rope inclines from Edge Hill—one for the passenger traffic to and from Lime Street, and two for the goods trains to and from the Docks—was stated by Mr. Woods to have averaged 8*d.* per train-mile in 1852.

Resistance to railway trains was an early subject of his experimental investigation. To determine the mean value of "railway constants," the British Association appointed in 1837 a committee, of which Mr. Woods was a member, together with Mr. Rennie, Sir John Macneill, Mr. Locke, Dr. Dionysius Lardner and Mr. Hardman Earle. Their first experiments, reported by Dr. Lardner to the Newcastle meeting in August, 1838, were made in the same year by observing the known action of gravity upon trains of given weight descending given gradients; the resistance could then be correctly deduced when a uniform velocity had been attained. Analysis of the engine power was less satisfactory; in Mr. Woods' opinion, the information as to the action of the steam in the cylinders not being sufficiently accurate. Moreover, with regard to the air resistance, not only had the frontage resistance to be considered, but also the friction of the body of air carried along with the train. In July and August, 1839, a second series of experiments were made. These were reported to the British Association Meeting at Plymouth in 1841, by Dr. Lardner and also by Mr. Woods, who had been largely instrumental in personally carrying out both series of trials.

On the 30th January, 1838, Mr. Woods read a Paper[1] before this Institution on the locomotive engines on the Liverpool and

[1] Transactions Inst. C.E., vol. ii. p. 137, and Minutes of Proceedings Inst. C.E., vol. i., 1838, p. 3.

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Manchester Railway. This Paper gave, according to the Report of the Council for 1840, some of the earliest and most accurate details on the actual working of locomotive engines, and seems to have been his first recorded connection with the Institution. In 1844 he laid before the Liverpool Polytechnic Society a review of the circumstances which had affected the consumption of fuel in the locomotives of the Liverpool and Manchester Railway from the opening of the line to the end of 1843. Again in 1850, while still in Liverpool, he published a pamphlet giving his observations on the consumption of fuel and the evaporation of water in locomotive and other steam-engines, and mentioned his personal knowledge of many facts connected with the history and development of the locomotive engine on the first field of its application to the transport of passengers and merchandise at high velocities—namely, the Liverpool and Manchester Railway. In 1848 he found the duty of 1 lb. of coke in the locomotives on this railway was 316,000 foot-pounds, equivalent to 6¼ lbs. of coke per horse-power per hour. On the "Swiftsure" locomotive he also made a trial at that early date of burning anthracite; but he found that, as soon as put on the fire, much of it became converted into a fine powder, which choked the fire-bars and tubes, and was carried up the chimney and fell unconsumed on the carriages of the train; steam could not be generated with it at the same rate as with coke.

Mr. Woods' relations with the Liverpool and Manchester Railway extended from the 1st January, 1834, to the end of the year 1852, a period of over eighteen years; for, although the Liverpool and Manchester Railway became incorporated with the Grand Junction Railway in 1845, he remained in the service of the amalgamated companies to design and carry out the various works specially identified with the interests of the Liverpool and Manchester Railway Company, for which Acts of Parliament had been obtained. The principal of these was the Victoria Tunnel of over 2 miles in length, passing under the City of Liverpool and connecting the Edge Hill Station with the Docks at the North End. Serious difficulties were experienced in the construction of this tunnel, of a similar nature to those afterwards encountered on a larger scale by the Metropolitan Underground lines tunnelling under buildings in London: it was completed in June, 1848, and included a commodious goods-station at its terminus adjoining the Waterloo Dock. Another work was the railway connecting the main line at Patricroft with the Liverpool and Bury Railway at Clifton, which was opened in January, 1850.

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Mr. Woods had previously designed and carried out the construction of the line through Salford and part of Manchester, which forms the connecting link between the Liverpool and Manchester and the Leeds and Manchester Railways. This line was completed in the year 1844.

In 1853 Mr. Woods left Liverpool, and settled in London as a Consulting Engineer on his own account. Before long he succeeded in establishing an extensive practice, and, in addition to works at home and elsewhere, his name may be specially connected with the development of the railway system in South America.

The subject of the choice of the best fuel for locomotives occupied much of his attention. Trials had been made in 1852 of burning coal in locomotives, instead of coke, which till then had been universally employed. In 1853, in conjunction with Mr. W. P. Marshall, he presented three joint reports to the General Locomotive Committee of the London and North Western Railway, giving the results of experiments carried out between London and Rugby on the passenger and goods engines employed on the southern and northern divisions of the line. The conclusion arrived at was that engines of 18 tons, with 700 square feet of heating surface, worked the trains as satisfactorily as those of 30 tons and 1,300 square feet of heating surface, with a close coincidence in the water and coke consumption when running with equal loads at equal speeds; and it was recommended that the passenger engines, weighing 23 tons in working order, should have cylinders 16 inches in diameter by 20 inches stroke, and driving-wheels 6½ feet in diameter; that the goods engines, weighing 25 tons in working order, and to draw a train of 264 tons, should have cylinders 16 inches in diameter by 24 inches stroke, and driving-wheels 5 feet in diameter; in both classes the weight on drivers not to exceed 10 tons; grate area, 13 square feet; heating surface in fire-box, 80 square feet; and in tubes, 900 square feet. The causes of the expenses on the southern division being heavier than on the northern were summarised. In 1854 a further joint report was presented on the use of coal in the locomotives of the southern division; and on the whole the conclusion seems to have been unfavourable to coal, for the larger portion of the then existing stock of engines. While 1 lb. of coke evaporated 8·65 lbs. of water, 1 lb. of coal evaporated only 5·83 lbs. In 1853, as subsequently stated by Mr. Woods, the duty of 1 lb. of coke in the London and North Western engines was 355,000 foot-pounds, equivalent to 5¾ lbs. per horse-power per

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hour, being a saving of ½ lb. on the consumption of 6¼ lbs., which he had found in 1848 on the Liverpool and Manchester Railway. In his experience there was no fixed ratio between the evaporative power of fire-box surface and tube surface in locomotive boilers; and whatever the ratio might happen to be it had nothing to do with economy of fuel.

Though the battle of the gauges in 1838, provoked by Mr. Brunel's adoption of 7 feet for the Great Western Railway, showed that the majority of the combatants sided with the present standard 4 feet 8½ inches gauge, Mr. Woods, however, seems to have held the opinion, now largely shared, that the Irish gauge of 5 feet 3 inches, or the Indian gauge of 5 feet 6 inches, would have been preferable to either of the two then engrossing almost exclusive attention. His subsequent experience comprised six railway gauges—5 feet 6 inches, 4 feet 8½ inches, 3 feet 9 inches, 3 feet 6 inches, 3 feet, and 2 feet 6 inches—besides tramways of still smaller gauge. In the colony of Victoria, where the 5 feet 3 inches gauge had been adopted and carried out for 453 miles, it was contemplated in 1872 to introduce a 3 feet 6 inches gauge for 600 miles of new lines projected. Mr. Woods, Sir Henry Tyler and Mr. T. E. Harrison, Past-President, independently of one another, were requested by Mr. Childers, then Agent-General for Victoria, to report on the proposal. All three agreed in recommending that the existing 5 feet 3 inches gauge should be adhered to for the new lines, rather than that a second and narrower gauge should be introduced; and the Colonial Government decided to follow their advice. The difference in cost Mr. Woods calculated would not have been more than £360 per mile in favour of the narrower gauge, against which would have had to be set the grievous disadvantages of a break of gauge. On the same grounds he was of opinion that in India it would have been preferable if branch lines had been made on the same 5 feet 6 inches gauge as the main lines, regarding it as a fallacy to consider that the cost of a railway is proportional to the width of gauge. Generally, indeed, it may be said that he looked upon a break of gauge as essentially a retrograde movement. None the less did it appear to him that a mistake had been originally made by the Indian Government in sanctioning lines equal and even superior to first-class English railways. In the United States, and in the republics of South America, he found that standard-gauge railways were constructed at less than half the cost of the Indian lines. Prior to 1873 he had made the Central Argentine Railway, 247 miles in length, of 5 feet 6 inches gauge for little over £7000 per mile, including sidings, stations, rolling-stock, and

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rails of 62 lbs. per yard. Yet earlier, about 1859 he had to construct the Copiapo Extension Railway of 27 miles, from Pabellon to Chanarcillo, in Chili, under instructions that the line was to be worked by mules, instead of by locomotives, owing to the steepness of the gradients. Mule traction proving a failure, he then designed engines light enough for the rails of only 42 lbs. per yard, with six-coupled driving-wheels having 4 tons on each wheel, and a four-wheel bogie carrying 8 tons, making 32 tons total. After the Antofagasta and Salar Railway of 2 feet 6 inches gauge and 78½ miles length had been laid with light rails for the light traffic anticipated, the traffic became much greater; and being then consulted, he had to advise that the line should be strengthened, though at a large extra expense.

Mr. Woods had also many years' experience of working round curves of even as little as 4 chains radius (264 feet) with engines having a four-wheel leading bogie with transverse motion, and without flanges on the leading driving-wheels. On the lines in South America so worked he had no instance of derailment at the ordinary speeds of 25 to 30 miles an hour. With the Santiago and Valparaiso Railway in Chili he was connected from its projection in 1850, and supervised the construction of materials for permanent way, iron bridges and working plant. The engines, built from his designs by Messrs. R. and W. Hawthorn, Newcastle-on-Tyne, had end-long play in the axle of the hind driving-wheels, to facilitate running round curves. For the Coquimbo line in Chili he afterwards sent out a tank engine with a two-wheel bogie truck, which proved highly satisfactory. For the Mollendo-Arequipa and Callao-Oroya Railways, made by the Peruvian Government, he superintended the materials sent out from Europe. Of the Fairlie engine he seems to have had a favourable opinion, owing to its whole weight being utilized for tractive power; he stated that it worked remarkably well on the Mexican Railway.

At the Plymouth meeting of the British Association in 1877 Mr. Woods was President of the Mechanical Section, to which he delivered an address on the Subject of "Adequate Brake Power for Railway Trains." Therein he reported the experiments made by himself, in conjunction with Colonel Inglis, R.E., for the Royal Commission which had been appointed in 1874 to inquire into the causes of accidents on railways. The experiments had been made with eight systems of continuous brakes; and from the results observed he drew up a list of thirteen conditions, which he considered indispensable for a continuous brake for heavy fast trains.

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Apart from railway work, he was also engaged in the construction of buildings in Peru, for which, like some other engineers, he considered a lighter construction was preferable to one more solid, with a view to withstanding earthquakes better. So long ago as 1851 he built at Pisco, on the coast of Peru, a wrought-iron pier 2,400 feet long, on screw piles, which suffered no injury whatever in the great earthquake that overwhelmed the city of Arica, in the north of Chili, 550 miles south of Pisco. In 1877 he constructed a quay wall at Bilbao without a cofferdam, by simply driving sheet piles in two rows at a distance apart equal to the width of the wall, and then removing the sand between them to the depth of 12 feet or 15 feet by means of a Woodford pump, and filling the trench with concrete.

Turning to yet another branch of engineering, Mr. Woods was Consulting Engineer to the Bournemouth Gas and Water Company from its incorporation in 1863 up to the time of his death. In 1869 he became Engineer to the Monte Video Waterworks in Uruguay, projected by local capitalists and subsequently taken over by an English Company. For the Corporation of the City of London he conducted a series of observations with Messrs. Joseph Quick and Son, in connection with the Water Bill of 1884, of which the principal object was to give householders the option of taking supplies by meter.

From this cursory sketch it will be seen that Mr. Woods was an engineer of wide experience and large views, who, during a lifetime co-extensive with the history of the railway world, was always found in the van of progress, and never allowed himself to relax his interest in the work going on in all branches of the profession. How lightly and happily he bore his weight of years was witnessed with wondering admiration by all who were privileged to accompany him in the visit paid on the 24th July, 1902, to the Blagdon Waterworks, in Somersetshire, constructed for augmenting the water-supply of Bristol. In that excursion, to which the Council of the Institution were invited by the President, Mr. Charles Hawksley, the Engineer of the undertaking, Mr. Woods tramped about cheerily with the rest of the visitors over all the ground they had to traverse on foot, for inspecting the work completed and in progress. Doubtless both his strength of character, soundness of judgment, and fertility of resource were largely aided by the singularly amiable disposition and quiet manner which distinguished him throughout his long, useful and active career, and made friends of all who enjoyed the privilege of his acquaintance. Mr. Woods married in 1840, Mary, daughter of Mr. Thomas

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Goodman, of Birmingham, by whom he had three sons and two daughters.

Reference has already been made to the Paper contributed to the Institution in 1838. On the 7th April, 1846, he was elected a Member. On the 21st December, 1869, he became a Member of Council, a Vice-President on the 20th December, 1881, and on the 25th May, 1886, he was elected President. His Presidential Address,[1] delivered on the 9th November, 1886, comprised a valuable account of the development of the railway system, not only in Great Britain and her dependencies, but also in foreign countries. He took at all times a warm interest in the welfare of the Institution, and even of late years, in spite of his great age, was a not infrequent attendant at its meetings.

*** The following deaths have also been made known since the 15th May, 1903:—

Members.

ATKINSON, JOHN; *died* 7 March, 1903.
FOULIS, WILLIAM; *died* 29 June, 1903.
GATES, WILLIAM HAYDEN; *died* 30 June, 1903.
MACTEAR, JAMES; *died* 8 June, 1903.
MORISON, GEORGE SHATTUCK; *died* 2 July, 1903.
STOREY, HENRY FRANCIS; *died* 18 June, 1903.
THOMPSON, WILLIAM GEORGE MACNEILL; *died* 12 May, 1903.

Associate Members.

BRUNDELL, RICHARD SHAW; *died* 9 May, 1903.
NOWLAN, JOHN; *died* 26 October, 1902.
O'SHAUGHNESSY, RICHARD GORMAN; *died* 9 May, 1903.
SALWEY, EDWARD RICHARD; *died* 3 May, 1902.
STARBUCK, WALTER; *died* 14 March, 1903.
STERLING, WILLIAM; *died* 23 March, 1903.

Associate.

WILKINSON, *Sir* JOSEPH LOFTUS; *died* 16 June, 1903.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 15th July, 1903.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 1.

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Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Development of Light Railways in Prussia.

(Glaser's Annalen, 15 May, 1903, p. 201.)

Since the decree of July 28th, 1892, under which light railways in Prussia were first placed upon an established basis, down to October 1st, 1902, a period of 10 years had expired, and on this account a report has been published by the Minister of Public Works giving an exhaustive review of the development and progress of these undertakings made up to March 31st, 1902. Such railways are therein classed either as street railways or as subordinate light railways. The former are chiefly passenger lines in towns; the latter may be regarded as feeders and branches to the great lines of communication. The railways belonging to the former class included on October 1st, 1892, in all seventy-nine separate concerns, with a total length of 544 miles. On March 31st, 1902, there were one hundred and forty-two undertakings, with a total length of 1,479 miles. Details are given as to the number of classes, gauge, motive power, etc., and it is observed that while the use of steam-power and horse-traction has steadily declined, there has been a corresponding growth in the employment of electricity. The total capital of these lines is set down at £24,169,139. Of the light railways of the second class, there were in 1892 only eleven, with a total length of 99 miles, while in 1902 the number had risen to two hundred and thirteen and the mileage to 4,254 miles. Similar statistics are given with respect to these railways, as in the case of street railways, and in contrast to the former class, the use of steam-power is here vastly in excess of all other modes of traction. The total capital is given as £17,703,156. Normal gauge lines have cost on the average £5,970 per mile, and lines of less than normal gauge on the average £3,530 per mile. It appears probable that undertakings of this type will steadily increase in number in Prussia.

G. R. R.

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The Electrical Working of the Mersey Railway.

(Railway News, 9 May, 1903, p. 746.)

A general description of the original undertaking as opened in January 1886 has already appeared in the Proceedings.[1] Of late years the popularity of the company has suffered from the receipts being insufficient to keep the line in good condition, and some time ago it was resolved to adopt electrical working. In July 1901 a contract was entered into with the British Westinghouse Electric Manufacturing Company to provide for the complete electrification of the railway on the most modern principles.

The new power-station is situated at Shore Road, close to Hamilton Square Station, Birkenhead; a brick chimney, 250 feet high adjoining, is a conspicuous landmark for miles around. The power-house is divided into boiler- and engine-rooms, the former containing nine Stirling water-tube boilers, fitted with Roney mechanical stoker-shoots, the coal being fed into these by shoots from five large hoppers, one for each pair of boilers and one for the odd unit. The coal is fed from the railway wagons direct into a breaker driven by a small Westinghouse electric motor, and thence on to the buckets of an endless elevator, which convey it to the top of the engine-room, and tip it into the coal-hoppers as required; these buckets on their return journey convey the ash from the grates to railway wagons. All the steam-piping, etc., is carried from the boiler-room through the partition wall into the basement of the engine-room. The engines themselves are above this, on a steel and concrete floor. They are five in number; three, each of 1,650 rated horse-power, are of the vertical cross-compound Westinghouse Corliss type, and run at 94 revolutions per minute, with steam at 170 lbs., and 25 ins. vacuum; under these conditions they can support an overload of 60 per cent. Each of these engines is employed to drive an electric generator of corresponding capacity, which generates electric current in either the direct or alternating form. Only direct current at 650 volts pressure is at present used.

From the main switchboard in the power-house the feeder cables, nineteen in number, pass down a shaft to the old ventilation heading, where they are divided, part going in one direction and part in the other. The lead-covered cables are secured to the rock face by substantial cast-iron clips. The feeders are carried into the main tunnel through cross headings, and connected to the positive and negative collector rails of the track. These are for the most part Vignoles rails, 100 lbs. per yard, of specially soft steel with high electrical conductivity; the positive rail, which is at high electrical pressure, is outside the track rails and elevated slightly above them; it is protected throughout by a wooden guard. The negative rail is in the middle, and rather lower than the track rails. The current is collected from these rails by means of

[1] Minutes of Proceedings Inst. C.E, vol. lxxxvi. p. 40.

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heavy iron sliding shoes, attached to wooden beams at the ends of motor-cars.

The new rolling stock comprises twenty-four motor-cars, and twelve of these being first-class and twelve third; and in addition thirty-three trailer-cars, of which eleven are first-class, seven third, and five composite; second-class accommodation has been abolished. The car bodies are 60 feet in length over the end sills, and each mounted on two bogie trucks and fitted with automatic couplings of the Buhoup three-stem type, a combination of draw-bar and centre-buffer coupling which forms the only cushion-buffer provided. The cars are on the corridor principle, being entered from the conductor's platform provided at both ends of trailer-cars and the rear end on motor cars. First-class trailers have a seating accommodation for sixty passengers, and motor cars forty-eight; the third-class cars accommodate a rather larger number.

Each axle of the motor cars is driven by a 100-HP. Westinghouse railway motor, through forged steel gearing of the ratio 56 : 20. The power of each motor car is thus 400 HP. at normal rating, and as there are two such cars to each train, the total power of the motors is 800 HP. This figure may, however, be largely exceeded on starting up hill. With the motive power thus spread over eight axles, very rapid acceleration, together with absence of slipping, is secured, while the permanent way is not so much stressed as by the ponderous steam locomotives formerly used. The method by which all the motors in the train are brought absolutely under the control of the motorman at either end of the train, is one of the most important features of the entire undertaking. The Westinghouse multiple control system is employed, involving the use of low-pressure electric currents to transmit the driver's will throughout the train, and electrically controlled compressed-air motors for the actual operation of the controllers, switches, etc.

With the new service the distance from Liverpool Central (low level) Station to Rock Ferry, 3¾ miles, with six stops, is covered in 11 minutes, or at a speed of 20·5 miles per hour, including stoppages, which is considerably faster than any other electric railway in this country, though the gradients are of a very severe nature.

A Water Arch for Locomotive Fire-boxes, Montana Central Railway.

(Engineering News, 19 March, 1903, p. 263.)

An interesting experiment in the application of a water arch to locomotive fire-boxes is being made by the Great Northern Railway. The arch consists of a steel box 6 inches wide, 3 feet long, but of varying shape to fit different fire-boxes. It is built up of ⅜-inch plates riveted together and strengthened by through stay bolts. This box is fitted between the side-plates of the fire-

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box in an inclined position with its lower end close to the tube plate, being supported at each side by two pieces of 2¼-inch steel pipe which pass through the side water-spaces of the fire-box by means of thimbles. The feed-pipes from the injectors are connected to the two lower supporting pipes, the water rising through the arch into two 2¼-inch copper pipes at the top, which discharge into the boiler. The water arch not only serves to divert the flame and gases from passing directly to the tubes but also acts as a feed-water heater and scale trap, the scale depositing in the arch, from whence it can be blown out while the boiler is under steam. To prevent burning of the arch through lack of circulation when the injector is shut off, an automatic circulating valve is used in a pipe connecting the front water-space of the fire-box with the bottom of the arch. While the injector is working, the pressure in the arch keeps the valve closed, but when the injector stops, the pressure of water in the boiler opens the valve and a continuous circulation of water is maintained through the arch. The results obtained are said to be very satisfactory in regard to reduction in fuel consumption, in boiler washing and repairs, and in the amount of scale.

A. W. B.

Dynamometer-Car on the Orleans Railway of France. HUET.

(Revue générale des Chemins de fer, March, 1903, p. 133.)

The Author describes a new dynamometer-car which has recently been put into service on the Orleans Railway. The appliances are so arranged as to give directly, by reading or the measurement of ordinates, all the information required in regard to the train under observation; they show at each instant the speed of the train, the resistance of the train and the total amount of this resistance since the commencement of the test. The appliances are of two kinds—namely, the indicating appliances for the speed, and the total amount of work done, and the registering appliances, tracing, on a sheet of paper unrolling itself, curves whose ordinates are proportional to the quantities to be measured. The curves thus traced represent the forces of traction or compression exerted by the train on the car, the speed, and the work done. The tractive or compressive forces are measured by means of dynamometrical springs which give the pull on the coupling hook or the compression on the buffers; the measurement of the speed and the unrolling of the paper is obtained by means of a connection with one of the axles of the car, and for the measurement of the work done a mechanical arrangement works out automatically the product of the forces by the length run.

The Author considers that the most original of the appliances is that used for registering the speed, and which consists of a steel sphere so arranged that it is able to revolve freely around its centre; two rollers of equal diameters have their axes in the horizontal diametrical plane of the sphere, and are fixed at right

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angles to each other, and are in contact with the sphere: one of the rollers travels at a constant and known speed, and the other travels at a speed proportional to that of the train. An angular speed is thus obtained, and by means of a third roller, arranged so that its axis is constantly parallel to that of the axis of rotation of the sphere, and to which is fixed a needle movable on a dial, the speeds are read off; and at the same time, by means of a pencil fixed by rods to the needle, the curve of speeds is traced on the paper roll.

Detailed descriptions of this and the other appliances, and of the car, are given with several figures and plates, and a copy of one of the records of a test.

J. A. T.

Acetylene for the Illumination of Railway Carriages.

D. BELLET.

(La Nature, 23 May, 1903, p. 385.)

The Paris, Lyons and Mediterranean Railway Company have erected a works at Bercy, near Paris, for producing the mixture of acetylene gas with Pintsch's carburetted gas, obtained from Boghead shale oil, used for lighting their carriages. The mixture consists of 25 per cent. of acetylene gas and 75 per cent. of the oil gas, which can safely be compressed to 10 atmospheres, without risk of explosion. The works for this purpose are shown in plan, and illustrated by details of the plant. In order to produce the gas from the Boghead shale, there are three benches of seven retorts each, fired direct with coke. In each charge, 110 lbs. of shale oil yield 353 cubic feet of gas, needing 1½ hour, and after depositing the tar the gas passes through condensers filled with oxide of iron and lime purifiers. The plant for the preparation of the acetylene gas is situated alongside the main gas-works, and contains three cylindrical generators, each 9·84 feet in height by 2·62 feet in diameter, capable of producing 530 cubic feet of gas per hour. There is also a condenser, a scrubber, two purifiers, a meter and a gasometer. In the Pintsch generators, which are of the non-automatic type, the calcium-carbide is placed by hand, a shovelful at a time, in the charging orifice, after having been broken up into lumps of a suitable size. The carbide falls into the water, and drops on to a grating, while the gas, which is at once evolved, rises to the upper part of the cylinder and passes out through an opening provided for it. The solid residue falls through the grating, and can be extracted from time to time by the manhole. The gas which enters the gasometer can then be passed to the meter-house for admixture with the oil gas. The admeasurement of the relative quantities of each gas is made by gearing together the two meters, so that a mixed gas is obtained in uniform proportions, and the gas in this form is stored in two gasometers, each of a capacity of 3,531 cubic feet. This gas has three times the

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illuminating power of the rich oil gas. The works, which are entirely satisfactory, are capable of producing about 5,000,000 cubic feet of the mixed gases annually. G. R. R.

A Steam Railway-Coach.

(The Engineer, 10 April, 1903, p. 372.)

A steam-driven motor railway-coach, belonging to the London and South Western and London, Brighton and South Coast Railways, has been built to run between Fratton and Havant. The coach body is carried on a channel-iron frame 56 feet long over all, and supported on two four-wheeled bogies. Accommodation is provided for 10 first-class and 32 third-class passengers, together with a van for 1 ton of luggage. The boiler and engine are placed in front of the latter. The boiler, placed in the centre, is of the vertical type with vertical and cross tubes. The engine has two cylinders, 7 inches diameter and 10 inches stroke; these are inclined, and the connecting-rods drive direct on the pins on the front wheels. It is calculated that the engine will give the coach a velocity of 30 miles an hour in 30 seconds.

A. W. B.

Continuous Brakes for Goods Trains. STABY.

(Organ für die Fortschritte des Eisenbahnwesens, 1902, p. 235.)

To render it possible to run goods trains at higher speeds than has been customary in the past, the number of brake vans accompanying the trains has been increased. This brings with it increased expense in brakesmen's wages, and in any case it is impossible for the brakesmen towards the ends of moderately long trains to hear with certainty the whistle given on the engine as the signal to apply the brakes. Experiments were made to determine how far behind the engine it was possible to hear whistles under various conditions, and the results are cited by the Author. They were very unfavourable. A solution of the problem of effectively braking goods trains is only to be hoped for by abandoning altogether the use of whistle signals and avoiding the necessity of employing brakesmen. This points directly to the need for introducing the continuous brake on goods trains. The Author recites the conditions necessary to be fulfilled by a suitable brake; that in use for passenger trains is not applicable, as the brake blocks are applied too quickly for wagons not coupled up absolutely tightly. As the old two-chambered air-brake appeared to fulfil most of the requirements set down by the Author, a train was made up, having amongst the vehicles a number of old passenger carriages fitted with this brake. The total weight of the train was 706 tons

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and the length 560 metres (1,837 feet). The number of wheels braked was one-fourth of the total number in the train. The coupling of the vehicles was such that there was a clear space of from ½ inch to 1 inch between the buffers. In the experiments, the working pressure was 4 atmospheres, and in applying the brake, the brake cock was put at once to the extreme position. The drop of pressure began in the last van 3 seconds after turning the handle of the brake cock on the engine. The train was brought to rest from various speeds and on different gradients. From a speed of 25 kilometres (15·5 miles) per hour, on an up gradient of 1 in 1000, the train was brought to rest in a length of 221 metres, (242 yards), the time taken being 57 seconds. On a down gradient of 1 in 150 the speed being 27 kilometres (16·8 miles) per hour, the length run before stopping was 494 metres (539 yards) and the time 94 seconds. On shutting off steam at a speed of 42 kilometres (26 miles) per hour and not applying the brakes, the train came to a stand after running 2,180 metres (1·35 mile) on the level in 455 seconds. In further experiments the end wagon was fitted with the Schleifer automatic valve, which opens when the pressure decreases by ½ an atmosphere (7·1 lbs. per square inch) allowing a quantity of air to escape, then closes; and opens and shuts thus alternately on continued decrease of the pressure. The Author supplies a drawing of this valve. Its action has a very favourable result on the length and time required in which to bring up the train. The regulation power of the brake in taking a train down heavy grades was also tested, and the results were perfectly satisfactory. The Author discusses the extent to which goods stock would require to be fitted up with the two-chamber air-brake to allow of various speeds, and makes an estimate of the cost of fitting and the probable economy of brakesmen's wages, etc., to be effected. The regulation of the brake pressure according as the wagons are emptied or loaded is of great consequence, and arrangements to effect this regulation are numerous. One such is described in the Paper.

J. G.

The Krizik Distance Signal with Controlled Home Signal.

A. PRASCH.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereins, 1903, p. 725.)

A trial installation of the Krizik railway-signal has been set up in the Rothneusiedel-Oberlaa section of the Royal Austrian State Railways. The modus operandi is as follows:—On entering a section the train completes an electric circuit by contact with a toothed bar projecting slightly above the surface of the one rail. This current excites a solenoid in the block apparatus at the signal-box in the rear, and, by attracting the movable core of this

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solenoid, cuts off the current in the solenoid governing the signal, which is thereby allowed to fall into the position of danger. On entering the next section the distance signal is set at danger in the same manner, whereupon the signalman in the second box is enabled to announce to the first box that the home signal there is clear, the same current simultaneously exciting the solenoid governing the first signal and lowering the arm. This cannot be done unless the second section is already blocked by the train; and the arrangement of the releasing push is such that it cannot be depressed more than once. Each signal-box is also provided with means for working a supplementary signal, which must be lowered by hand before the oncoming train may enter the section, the object being to show that the signalman is aware that the section is clear. The trial installation being mounted on a single line in the position next Oberlaa station, provision is made for the admission of trains to the final section to be controlled from the station, which is fitted with a control apparatus for announcing the oncoming train, and with a contact lever governing the signal at the entrance to the final section. In the details of the apparatus, means are provided for interposing resistances into the circuit of the signal-arm solenoid so as to enable the arm to be lowered without undue shock, and there are also means for preventing waste of current.

C. S.

The Preservation of Sleepers by the use of Trenails.

(Le Génie civil, vol. 43, 1903, p. 60.)

This Paper describes the system employed by Mr. Albert Collet on the Paris-Lyons-Marseilles Railway, in using hollow-screwed trenails for the preservation of the sleepers. These trenails are made of hornbeam 53 millimetres (2·08 inches) in diameter at the head, and 35 millimetres (1·38 inches) at the foot; the lower part being externally screwed, and strengthened at the end by a steel ferrule. The length is 150 millimetres (5·9 inches), and the whole trenail is creosoted before use.

The holes in the sleepers are bored and tapped, and the trenail screwed in by a portable drill-head, which is driven from an electric motor by a flexible coupling; the whole apparatus having been specially designed for the purpose.

Some spruce sleepers laid down in 1888, and trenailed by this process in 1896, are still in good condition; whereas others of the same age, which were not trenailed, are now useless.

The paper is illustrated by seven figures in the text.

H. I. J.

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Houses for Railway Servants.

(Organ für die Fortschritte des Eisenbahnwesens, 1902, p. 117.)

The want of suitable dwelling-houses for railway servants of the middle class has been experienced on the Prussian-Hessian and other Government railways in Germany, and the present Paper contains, in addition to a general discussion of the question, descriptions and drawings of three designs which gained premiums in a competition, the subject being a house for one or two families, the sum of the areas of the rooms not to exceed 90 square metres (969 square feet). The cost of a house for one family was not to exceed 9,500 marks (£475), and of that for two families 16,000 marks (£800). The premiated designs are all for two families. There are certain features common to the three designs. Each has cellars, ground and first floors, attics and outbuildings. The living rooms for each family are on the ground and first floors, and the cellars and attics are in common. The staircase is in one corner of the building. The rooms on the ground and first floors of the first prize design are as follows :—

Kitchen 3 metres × 3·7 metres (9 feet 10 inches × 12 feet 2 inches).
Pantry 1 metre × 3·7 metres (3 feet 3 inches × 12 feet 2 inches).
Room 4·5 metres × 4·725 metres (14 feet 9 inches × 15 feet 6 inches).
Room 4·5 metres × 4·855 metres (14 feet 9 inches × 16 feet).
Two bedrooms, each about 3·5 metres × 4 metres (10 feet 6 inches × 13 feet 1½ inches).

The height from floor to floor is 3·4 metres (11 feet 2 inches). The estimated cost of this design was exactly the £800 mentioned in the conditions of competition.

J. G.

Electric Trolley-Haulage without a Track at Grevenbrück, Westphalia. VOIGES.

(Deutsche Bauzeitung, vol. 37, No. 31, p. 202.)

Trackless electric trolley haulage, on the Schiemann system, is employed at the Grevenbrück limestone quarries, Westphalia, for conveying the quarried stone to the railway station, a distance of 1½ kilometres (1,640 yards). The two overhead wires are of hard copper of 70 square millimetres section (0·108 square inch), 50 centimetres (20 inches) apart, and supported at a height of 5½ metres (18 feet) above the roadway by standards 30–35 metres (33-38 yards) apart. The contact shoes are fitted with universal joints, and the trolley poles are supported by spiral springs, in such a manner that the locomotive and train of trucks can move to the side of the road in order to pass other vehicles. The

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rolling stock consists of a locomotive carrying two 17-HP. motors (weighing 5½ tons), and six 5-ton trucks (tare 2 tons each), two of which trucks form a train. The locomotive wheels are 90 centimetres (3 feet) in diameter and 15 centimetres (6 inches) wide in the tire; and the truck tires are 12 centimetres (4¾ inches) broad. The maximum permitted speed is 6 kilometres (3¾ miles) per hour, and the brakes are sufficiently powerful to stop the train within 3 metres (10 feet). The specific pressure on the wheels of the locomotive is 528 lbs. per inch of breadth, and for those of the trucks 803 lbs., or about the same as in an 18-ton Aveling and Porter steam-roller. These pressures are less than those of ordinary loaded road wagons, so that no undue wear of the roadway is produced, more particularly since the trucks and motors are mounted on springs.

The train easily mounts the gradient of 1 in 23 leading to the Lenne bridge, and also traverses the approaching curve (radius 26 feet) with a slight increase in the consumption of current. The cost of haulage per ton-kilometre is given as 25 pfennige (3*d.*), the supply of current costing 25 pfennige per kilowatt-hour from a neighbouring generating station. Horse-traction costs 30 pfennige (3¾*d.*), so the system offers an advantage in this respect, which could be increased by the installation of a generating plant, increasing the size of the wheels and reducing the weight of the trucks.

C. S.

The Testing of Bridges. RABUT.

(Paper read before the Congress of Applied Mechanics, held at Paris in 1900.)

The Author describes his experimental work in connection with bridges, more particularly in ascertaining the amount of deformation of the various members of a structure under moving loads. In Chap. I. he describes the various apparatus used by him; in Chap. II. the application of his methods; and in Chap. III. the actual results of the experiments.

About any point of any member of a structure, the deformation under a load can theoretically be measured in three directions, but in practice generally in one direction only, viz.: in that of the greatest dimension of the member. Of these, lineal displacement is the easiest to measure; and the apparatus used, the Rabut recorder, registers any movement in this direction exceeding $\frac{1}{10}$ of a millimetre (0·0039 inch). This recorder consists of a cylinder covered with paper which is moved at a uniform speed by a train of clockwork, and upon which a special pen fixed upon the end of a lever traces a line. The opposite end of the lever is carried on the base of the recorder, and from a point, which, as a rule, gives a leverage of 20 to 1, a connecting rod is attached through the

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medium of a spring and wire to the portion of the structure which is being tested. The sensitiveness and precision of this recorder allows of a study of not only the variation of the bending, but also of the vibrations of various degrees of magnitude. The Author then describes the system of measuring angular deformation by means of a telescope fixed to one end of the bridge and sighted on some immovable mark at a known distance.

To obtain the measure of any local deformation requires a more delicate apparatus, necessitating readings to $\frac{1}{100}$ of a millimetre (0·00039 inch). The apparati described are those of Messrs. Ustéri; E. Bourdon; Schroeder, van der Kolk, and Kist; Mesnager; and Rabut. In all these the main principle is the same, the apparatus being made in two parts, each of which is fixed to a separate part of the portion of the structure which is being measured, the amplification of the movement being obtained by the use of multiple levers.

In Chap. II. the Author describes the application of his methods of test for permanent loads, overloads, the variations of temperature, wind, etc., of which the influence is sometimes negligible, and sometimes may exceed the load itself.

In Chap. III. the Author states that the results obtained are very numerous, the experiments extending over 10 years, and are, moreover, very difficult to classify: he therefore considers successively each of the most important characteristics presented by a structure under deformation, and states that all bridges will fall into two classes, by either the presence or absence of such characteristics. He also deals with various diagrams taken from bridges subjected to different classes of loads, and points out the influence of the vibrations set up in structures by fast moving loads; the effects of such vibrations being in some cases as much as the bending moment due to the load itself. He also points out the difference between the calculated results due to certain loads, and the actual results obtained; such difference in one particular case being sufficient to save the pulling down and replacement of a cast-iron viaduct which, from calculation, had been condemned as being of insufficient strength.

In conclusion, he impresses upon engineers the necessity for making an alteration in the usual calculations for the design of structures, a great error arising from the neglect of making use of the solidarity which he has proved to exist between the various members composing a metallic structure.

The paper is illustrated by 17 diagrams and figures in the text.

H. I. J.

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Cement-Concrete Railway Bridge with Jointed Arches over the Rosso Creek near Senigallia.

(Giornale del Genio civile, Rome, September, 1902, p. 417.)

On the railway from Bologna to Foggia the tract of 75 miles along the coast of the Adriatic between the rivers Cesano and Tronto was visited in October 1897 by heavy rainfall in The Marches, which caused all the rivers to overflow their banks near their mouths, and, aided by tempestuous seas, to flood a vast extent of country. The railway embankments near the coast were thereby cut through in various places, and several of the bridges were destroyed. All traffic was stopped for twenty-five days, during which, pending the reconstruction of the former bridges on their original sites, the line was diverted over temporary timber bridges erected alongside. As an example meriting special mention, the rebuilding of the bridge near Senigallia over the Rosso creek, 111 miles south-east of Bologna, is described in detail, and is illustrated by figured engravings, with a couple of photographs. The original bridge had two openings, each 10 metres (33 feet) wide; the bed beneath them was about at sea-level. It had been constructed with a view to leaving the creek open, so that the channel might serve as a by-wash for discharging any overflow from the right bank of the river Misa, which enters the Adriatic at Senigallia; but the creek had remained almost dry for many years, until in the flood of 1897 it was converted by the overflow into a torrent of such violence as to carry away the whole of the bridge, with the exception only of the left abutment.

As a rule masonry is preferred to iron or steel for the bridges on the Southern Railways of Italy, especially where near the sea. The new Rosso bridge was therefore built of cement-concrete, with three low arches of 22 metres (72½ feet) span and 2·2 metres (7¼ feet) rise; the level of the rails was raised 55 centimetres (22 inches), and the bridge was built wide enough for a double line. The foundations of the abutments and piers, commenced in October 1899, were carried down by means of compressed air to a bed of gravel, or of clay and sand, at depths varying between 14·16 metres (46½ feet) and 12·08 metres (39½ feet) below sea-level. Up to 2·75 metres (9 feet) from bottom, the working-chambers were filled in with concrete, above which was built a walling of brick, encasing a core of stonework embedded in concrete. The stonework backing behind the abutments is founded on piles, of which the nearer rows are vertical; and by inclining the pile-driver the rows further back were driven raking outwards towards the toe, for resisting the thrust of the arches more effectually.

The arches were built on timber centering, which was carried on piles driven in clay to a depth of about 7·3 metres (24 feet) below sea-level. The springing of the arches is 1·5 metre (5

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feet) above sea-level; and at the crown the centering was raised 50 millimetres (2 inches) higher than the intended rise of 2·2 metres (7¼ feet), so as to allow for settlement on completion. The arches are 8·58 metres (28 feet) long, and each is composed of twenty-two voussoirs of this length, which average rather more than 1 metre (40 inches) in width, and taper in depth from 1 metre (40 inches) at the impost and haunches to 0·8 metre (32 inches) at the crown. Starting at the crown, and numbering from 1 to 11 in each direction, an expansion-joint was provided at the crown itself between the two No. 1 voussoirs, by embedding and clamping in their contiguous faces iron hinges or bearing-boxes, like those adopted for the Munderkingen bridge over the Danube in Würtemberg.[1] The boxes are built up of plates, channel bars, and angle bars, and carry longitudinal steel rails bearing against each other; the convex cylindrical surface of one rail bears in a corresponding shallow groove extending along the length of the opposite rail, thereby admitting of a minute turning movement like that on a horizontal hinge-pin. A similar expansion joint was provided at the springings, between each No. 11 voussoir and the impost against which it abuts. The rest of the voussoirs were then made in the following order, so as progressively to distribute their weight uniformly and symmetrically over each half of the centering during the construction of the arch:—first the four pairs of odd Nos. 9.9, 3.3, 7.7, and 5.5; and then the intermediate five pairs of even Nos. 8.8, 4.4, 6.6, 2.2, and 10.10. The voussoirs were moulded in their places between wooden boards propped on edge. Into the troughs so formed was tipped and rammed the cement-concrete, of which the proportions were 425 kilograms best Portland cement to 0·5 cubic metre sand and 0·8 cubic metre ballast (937 lbs. to 17·66+28·25 cubic feet). Test pieces made of 1 cement to 3 sand by weight were required to stand at least 25 kilograms per square centimetre in tension and 250 in compression (356 and 3,560 lbs. per square inch) after 28 days' weathering. The maximum pressure when the arches are loaded to the utmost by trains is calculated at 22·5 and 21·5 kilograms per square centimetre (320 and 306 lbs. per square inch) at the crown and imposts respectively; and 26·3 kilograms per square centimetre (374 lbs. per square inch) at the haunches, when the moving load extends over only one half of the span. The whole of the concrete for the arches, amounting to about 600 cubic metres (nearly 800 cubic yards), was mixed mechanically in a sloping cylinder rotating on rollers, whereby regular delivery and uniform quality were ensured.

The construction of the arches was begun on 11th April, and finished on 13th May 1901. The centerings were struck on 14th June, when they had already sunk on an average 35 millimetres (1·40 inch) under the load of the arches; the crown then came

[1] Minutes of Proceedings Inst. C.E., 1894, vol. cxix. pp. 224–5.

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down 6 millimetres (0·24 inch) more in the middle arch, and 10 millimetres (0·40 inch) in each of the other two. The total settlement of each arch was thus covered by the 2 inches extra rise given to their crowns at the outset. Arched spandrels built over the haunches extend to about a quarter of the span from each springing; and into the expansion-joints was run liquid cement-mortar, so as to cover the hinges completely. Over the whole was spread a layer of asphalt to carry the permanent way. On 29th August the bridge was tested by placing on different parts two locomotives coupled together front to front, which afterwards ran over it at increasing speeds. The deflection was little more than a millimetre (0·04 inch), which was completely recovered by the elasticity. The bridge was opened for traffic the same day.

A. B.

Roller-Weir at Schweinfurt-on-Main. CARSTANJEN.

(Deutsche Bauzeitung, 1903, p. 645.)

This weir is erected in a lateral channel of the River Main, 18 metres (59 feet) in width, and consists of a number of sections of iron plate riveted together to form a cylinder of pear-shaped cross section, 10 feet in diameter. The ends fit in recesses in the masonry, and are provided with toothed crowns which engage in racks on the inclines. The cylinder is raised and lowered by means of wire ropes slung around grooved pulleys at each end, the ends of the ropes being attached to self-locking worm winding-gear provided with adjustable rope pulleys to take up any slack of the ropes. Leakage is prevented by the attachment of an iron girder to the sharp edge of the cylinder resting against the weir bottom; and the cylinder is retained in position by pawls engaging with the toothed crowns at each end. The shape of the cylinder and the fact that, in ascending, it moves in the direction of the stream, combine to minimise the consumption of motive power. In addition, the cylinder is pierced by a central longitudinal tube, open at both ends, which fills with water when the cylinder is lowered, and thus facilitates submersion, the water then running out at the ends into the tail stream. All the moving parts are out of the reach of ice forming in the lower stream, and the hoisting machinery is found to work at a satisfactory speed, even when the water is at its highest, and although the cylinder weighs 72 tons.

C. S.

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New Lock at Port-à-l'Anglais. A. M. J. Alby, M. Inst. C.E.

(Annales des Ponts et Chaussées, 1902, p. 5.)

The traffic on the Upper Seine having very considerably increased, and one lock being found to be insufficient, it was decided to build a second lock, the details of which are described in this Paper.

The lock is 180 metres (590 feet) long, and 16 metres (52 feet) wide. Full details are given of the construction of the lock, sluices, and gates; but in the opinion of the Author the most interesting portion of the work is the means adopted for working the gates. These are arranged to be worked either by hand, or mechanically by means of turbines. The hand-gear is worked from a crank through a train of wheels to a pinion gearing with a quadrant fixed to the gate. The drive from the turbines is taken through a friction clutch controlled by a lever, and means are provided for the clutch to be automatically thrown out of gear when the gate is fully opened or closed. The turbines are of normal type, and are worked by the difference in the head of water on the two sides of the gates, giving 15 HP. on a head of 2·2 metres (7 feet).

The lock was opened on the 7th May, 1902, the total expenditure on lands and works being £78,694.

The Paper is illustrated by three plates of detail drawings.

H. I. J.

Equipment of Large Mercantile Ports. Edilio Ehrenfreund.

(Giornale del Genio civile, Oct.–Nov. 1902, pp. 465 *et seq.*)

As an engineer on the staff of the Italian Government Inspector General of Railways, the Author was deputed to visit the chief continental mercantile ports in Europe, with a view to comparing their appliances with those at present in use at Genoa and other Italian ports, and to getting over the principal difficulties encountered herein. The results of his enquiries are presented in an elaborate report, accompanied by forty-six illustrations of mechanical appliances and ports.

Power.—For discharging cargoes the power working the various mechanical appliances is almost always supplied from a central station. Of the manifold advantages attending this plan the most important is the large number and diversity of the powerful appliances that can thereby be worked, all of which are ready for immediate use; while each individually can be worked independently of the rest, and for as short a time as desired. With few exceptions each requires only one attendant. Simplicity and expedition are combined in a high degree. The several

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advantages and disadvantages of distributing the power by hydraulic pressure, electricity, steam, or compressed air, are reviewed in elaborate detail; and are exemplified by the practice and experience of the various ports visited, at which one or more of these four modes of transmission is in use. Thus far gas-engines have not been employed.

Antwerp has 137 appliances, all worked by water pressure. Marseilles has 99, all hydraulic: 39 are fixed cranes; 59 are movable, supplied through telescopic service-pipes; and one is a 120-ton derrick. Rotterdam, beginning in 1879 with water pressure, has 15 hydraulic appliances; and from 1890 has added 30 electrical. To guard against freezing, valves are provided in the mains for isolating and emptying lengths temporarily idle; self-closing safety stop-valves are added for preventing the accumulator from running down. In winter the water in the storage tank at the central pumping station is warmed by steam to 24° C.= 75° F., so that even in severest frost the temperature at furthest extremity of mains is generally not below 2° C.= 35° F. Valves, expansion pipes, cocks, etc., are placed in brick pits, which in winter are warmed by gas-burners. Cologne has 37 hydraulic cranes, and 9 steam; 10 lifts inside warehouses, and 3 capstans. Genoa was supplied with water pressure in 1887, and has now 57 hydraulic appliances; electricity is employed in private establishments only. For fear of frost, hydraulic pressure has not been adopted in Hamburg; but 280 steam cranes are in use, mostly self-contained carrying their own boilers. A few, worked by steam from a central source, have a vertical single-acting cylinder, with inverted multiplying tackle on the Armstrong plan, and with no expansion. It is their simplicity and facility of handling that render these, in the opinion of the Hamburg management, preferable to the rest which drive through worm and spur gearing, with attendant noise and jarring. From 1890 electricity has been added, which is now working 101 appliances. Mannheim has a considerable number of steam cranes, all self-contained with their own boilers, which seems the most convenient plan, owing to their great distance apart along the extended stretch of quays. Electric cranes have been placed on wharves where the work is heaviest. Altogether there are now 105 discharging appliances, steam or electric. In ports having their own central station, electric power is generally supplied by continuous current, with storage batteries for use when only a few cranes are working: as at Mannheim and Rotterdam. Even with compressed-leather pinions the speed-reducing gear makes great noise, and jar enough to set the whole crane in a tremor. On shutting current off, the momentum of the revolving parts prevents their stopping immediately; and, notwithstanding brakes, the movements are not controlled with such ease and precision as by hydraulic pressure, while some are even dangerous.

Low Travelling-Cranes, from 10·7 to 10·9 metres (35 to 36 feet) high, and 9·5 to 10 metres (31 to 33 feet) radius, need so large a

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base for stability that they are generally too cumbersome on quays, except where there is ample room apart from the ordinary railway-lines. At Genoa, where the quays are crowded with railway traffic, they have to travel on the standard gauge. At Antwerp they have a wider track of 2·4 metres (7 feet 10½ inches); and at Mannheim and other Rhine ports 3 metres (9 feet 10 inches). At these last they are not required to be taller than just to clear the tugs that work the inland river navigation.

Gantry Cranes, whether straddling over one or two railway tracks, have the advantage over the low cranes of leaving the wharf clearer, and of having to slew through a smaller angle, because the trucks run nearer to the wharf edge; both time and power are thus saved. Antwerp has 83, built in Belgium, of 4 metres (13 feet 1½ inches) gauge, lifting from ¾ up to 4 tons with a water-pressure of 50 kilograms (700 lbs. per square inch). Here the hydraulic press forms the lower half of the crane-pillar, and receives the bending strain due to the load; it is supported by a collar-bearing at top, and is stepped in a cross-bar at bottom, so that it turns with rubbing friction in both bearings. At Genoa and Savona a better plan is adopted, with platform revolving on rollers, whereby rolling friction is substituted for rubbing; the hydraulic press is inside the pillar, free from bending strain; the cabin and levers revolve with the platform, and through its hollow centre-trunnion pass the pressure and exhaust-pipes, with stuffing-box and elbow-pipes; gauge 4·055 metres (13 feet 4 inches), load 1½ ton. Electric gantry cranes are in use at Copenhagen, Dortmund, Düsseldorf, Rotterdam, and on the old pier at Genoa. Those at Düsseldorf are 9 metres (29 feet 6 inches) gauge, lifting 3 tons at 11·75 metres (38 feet 6 inches) radius. Rotterdam has 29 of 8·5 metres (27 feet 10½ inches) gauge, lifting 2½ to 4 tons, with a current of 440 volts. Here the back leg alone travels on a rail, and the front leg along the granite coping of the quay wall, thus allowing surface-water to run freely off the wharf.

Great facility and expedition of unloading are gained with the one-legged gantry—nicknamed *capra zoppa*, "lame goat"—which travels on one rail laid along the edge of the quay, while its inner end is carried on a rail raised about 5 metres (16 feet) above ground, running along the front wall of sheds or stores, or supported on a row of pillars. Presenting the least amount of obstruction upon the quay, this gantry is specially suitable where there are warehouses fronting on quays not wider than 12 metres (40 feet). It would be highly advantageous for Genoa, where some of the quays are no wider than 10 or 11 metres (33 to 36 feet); the present gantry-cranes being only wide enough to span a single line of rails, their inner leg has to travel between two tracks, which have to be so much wider apart that no room is left for carts to get by. On other quays there is not even room for a two-legged gantry. Cologne has 30 of the one-legged gantry-cranes, worked by water pressure; Hamburg and Mannheim have many, either hydraulic or electric or steam.

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Elevators and Conveyors.[1]—Mannheim has 13 electric bucket-elevators, either stationary or travelling, which discharge grain at the rate of 40 to 60 tons per hour, with 15 metres (49 feet) height of lift, requiring about 15 I.HP. Bucket-elevators at Venice are hung by steel-wire ropes from travelling gantry-cranes; a small electric motor at top of elevator drives the buckets and also a band conveyor, with an expenditure of 7 I.HP. for 50 to 60 tons of grain per hour; the arrangement is more compact than that at Mannheim. A coal-elevator raising 70 tons per hour at Altona on the Elbe, near Hamburg, has buckets of 16 kilograms (35 lbs.) capacity, which are carried on a band made of seven thicknesses of gutta-percha covered canvas. Duckham pneumatic elevators are employed at Hamburg for transhipping grain into barges for the inland navigation. The grain warehouses erected at Genoa in 1901 have four, arranged for exhausting simultaneously from two vessels on opposite sides of the same jetty. Each is worked by a compound engine of 140 to 150 I.HP., driving a pair of double-acting pumps, which exhaust from 50 to 60 tons of grain per hour. While thus requiring much more power than bucket-elevators doing the same work, the pneumatic elevators present many advantages in respect of labour and convenience; during rain they can be kept going without the grain getting wet.

Elevators for coal and minerals, by Hunt of New York, are employed at Copenhagen, at Ludwigshaven on the Rhine, and at various works in Germany; one is erecting at Savona. A self-tipping and self-righting bucket is wound up by a rope passing over a trolley, which is then itself hauled up by the same rope along a straight arm or cantilever inclined at 30° to the horizontal. At Copenhagen the arm is a parabolic arc, which simplifies the working. The speed is 40 tons per hour in 25 lifts, and can be increased to 60 tons with buckets of 2-ton capacity. As the aggregate fall of the load discharged amounts to 15 to 17 metres (50 to 56 feet), the value of lump coal may be impaired by breakage. The appliance is costly and bulky; when built for travelling, it covers an area of 6 by 12 metres (20 by 40 feet), and is 20 metres (66 feet) high. To the Hunt elevator is generally added an automatic delivery truck, running on an overhead railway which slopes 3 in 100 downwards from the elevator stage; the descending loaded truck is stopped at any desired place on the incline by an adjustable sliding buffer connected with a heavy counterpoise, which takes up the momentum; flap doors forming the sides of the truck are at the same moment unlatched by a self-acting trigger, the load drops out, and the counterpoise propels the empty truck up the incline, back to the charging stage.

In elevators by Brown, of Cleveland, U.S., a trolley is hauled

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[1] Of those already described in Mr. Zimmer's recent Paper on "Mechanical Handling of Material" (*ante*, p. 59), it is unnecessary to do more than summarize the working results, ascertained by Mr. Ehrenfreund.—A. B.

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outwards and inwards along a bridge or cantilever by a pair of winding drums running opposite ways; it carries a bucket-hook, with a locking arrangement for safety while travelling; a third winding-drum lifts the bucket. The recently erected elevators at Genoa have a bridge or cantilever of 58 metres (190 feet) length, along which the trolley runs 53 metres (174 feet); they are worked by electricity, and can discharge an average of 40 tons of coal per hour. At the Rothe Erde Iron Works, near Aquisgrana, a travelling gantry of 9 metres (29½ feet) gauge carries on each side a cantilever, along which a trolley runs altogether 100 metres (328 feet) at 3 metres per second (say 7 miles an hour), for lifting 5-ton loads of long girders or bar iron. In four elevators at the Krupp Blast Furnaces at Rheinhausen, near Duisburg, the bridge consists of an overhead lattice girder, carried on two travellers 60 metres (197 feet) apart, and sloping 1 in 8, up which a trolley has a run of 90 metres (295 feet). These have been over six years in use, landing iron ore in a bucket of 1 cubic metre (35 cubic feet) capacity, which is lifted 17 metres (56 feet), run ashore, emptied, and run out again to reload, all in one minute. The average delivery per hour ranges from 45 to 50 tons, and may attain a maximum of 68 tons.

Of the various kinds of buckets the self-acting are the most diversified; the Jaeger construction is described in detail. An automatic bucket to contain 1 to 2 cubic metres (35 to 70 cubic feet) weighs from 1,200 to 1,600 kilograms (24 to 32 cwts.), and costs from 1,800 to 2,500 lire (£72 to £100). They are largely used at Mannheim, where they can dip into any part of the open Rhine barges, and the attendant can see they get properly filled; for sea-going vessels with hatches they are not so suitable.

Coal-tipping cranes, for discharging railway wagons direct into a ship's hold, are coming into use. At Ruhrort the tilting platform is 5 metres (16 feet) above quay, and ten wagons per hour are tipped by each crane. Rotterdam has three coaling cranes, two hydraulic and one electric, in which the platform is lifted from the quay by steel-wire ropes to a height of 12·5 metres (41 feet) for tipping; in busy times fifty-six 12-ton wagons are discharged in eleven hours. Antwerp has one such coaling-crane, worked by water-pressure.

Working Expenses.—Particulars are given for Hamburg, Rotterdam, and Antwerp: but too many varying factors and conditions are involved to admit of forming any estimate therefrom for other ports. Similarly the choice of plans must be determined by local circumstances. The requirements of the work stand foremost; the cost is secondary. The appliances ought to be both provided and worked by the port administration; any seeming loss is then recouped by enhanced revenue from port dues.

Number of Appliances.—The majority of the cranes are movable, lifting 1½ to 2½ tons; those of greater power are generally stationary. The largest yet existing is a 150-ton steam derrick

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at Hamburg, which has been tested up to 175 tons. Antwerp has 83 travelling cranes in 3,500 metres (2·175 miles) of quays, or 1 per 42 metres (138 feet); Rotterdam 30 in 2,200 metres (1·367 mile), or 1 per 73 metres (240 feet). At Hamburg many appliances have to be working simultaneously for the large inland navigation by barges; there the proportion is 574 in 13,885 metres (8·63 miles), or 1 per 24 metres (79 feet). Generally ports open to sea-going vessels have 1 crane per 50 metres (164 feet): so that two or three can be kept at work on an ordinary ship 100 to 150 metres (330 to 490 feet) long. Cologne has 160 appliances in 4·5 kilometres (2·796 miles), or 1 per 28 metres (92 feet). Genoa is not yet among the best equipped ports; almost all coal is still discharged by manual labour; on the general merchandise quays there are 62 appliances in 4,560 metres (2·834 miles), or 1 per 73 metres (240 feet); but they are no longer adequate to the increased railway traffic.

Storage.—Coal and minerals are stored in open yards. At Altona is a warehouse for 12,000 tons of coal, comprising fifteen silos, all 15 metres (49 feet) high; nine are 8 × 8 metres (26¼ × 26¼ feet) in section, and six are 8 × 6 metres (26¼ × 19⅔ feet); but in silos coal is more liable to heating and spontaneous combustion. Antwerp has sheds in four bays with open sides, aggregating 50 metres (164 feet) width, and covering 100,000 square metres (25 acres); for protection from rain, wind, or cold, the sides can be closed by revolving shutters. Hamburg has iron-built stores; those for the large winter fruit traffic are warmed by steam, and have double roofs and double walls with a space between, which is packed with peat. At Genoa is a grain warehouse built of Hennebique armoured cement, to contain 30,000 tons in 218 rectangular bins, which are 17·6 metres (57¾ feet) high, and are ventilated by compressed air; ground area 4,576 square metres (1·13 acre). The grain warehouses at Mannheim and Venice are furnished with silos for only a portion of the grain stored, owing to risk of its suffering deterioration therein; the rest is spread on floors in shallow layers, to get well aërated. At some ports on the Rhine unfavourable experience of silos has resulted in demolishing them, and reverting to spreading the grain on floors.

Traffic by Water and by Rail.—In six ports the traffic during 1900 was shared by water and rail (see p. 371). Antwerp, Marseilles, Genoa, and Mannheim are chiefly railway ports, in the sense that the primary consideration is the railway traffic, to which the port arrangements are made subservient. For these four the general principles of the management are summarized and criticized. Mannheim, 567 kilometres (352 miles) from the sea, is now the terminus of the great Rhine navigation: whence the magnitude of its port. The arrangements of the railway lines on the quays at Mannheim, Antwerp, Marseilles, and Genoa are described and commented upon.

Sorting Grids.—At Mannheim the existing accommodation for sorting, though laid out for 8,000 wagons, is already too cramped

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TRAFFIC BY WATER AND BY RAIL IN SIX PORTS DURING 1900.

Port.	Tonnage by Water.			Tonnage by Rail.			Ratio Rail to Water. Per Cent.
	Landed. L	Put on Board.	Total. W	Arriving.	Despatched. D	Total. R	
Hamburg[1]	9,850,615	4,581,553	14,432,168	285,634	398,117	683,751	R : W = 5
Antwerp	7,023,791	[2]	[2]	3,038,010	3,285,085	6,323,095	D : L = 47
Rotterdam[1]	10,540,256	[2]	[2]	962,219	812,392	1,774,611	D : L = 8
Marseilles	3,814,751	1,885,324	5,700,075	1,546,160	1,771,561	3,317,721	R : W = 58
Genoa	4,548,468	857,740	5,406,208	469,980	3,190,450	3,660,430	R : W = 68
Mannheim	4,547,000	785,000	5,332,000	923,442	2,805,097	3,728,539	R : W = 70

[1] Maximum traffic is between sea-going vessels and inland navigation.

[2] No statistics.

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for the traffic, which during 1900 reached a daily average of nearly 2,200 wagons, including loaded wagons despatched and arriving, and empty returns. A second sorting-yard is now constructing, close to the present, and of large size for growth of traffic. Pertaining to the port are 19·8 kilometres (12·30 miles) of quays, whereof 18·155 kilometres (11·28 miles) are furnished with 100 kilometres (62 miles) of railway lines. At Antwerp the quays on the Scheldt and round the basins amount to 17 kilometres (10·56 miles), with 71 kilometres (44·12 miles) of railway; the southern station covering 25 hectares (62 acres) has 54 sidings for sorting by gravity, comprising 85 kilometres (53 miles) of line; the dock station covering 55 hectares (136 acres) has 170 kilometres (106 miles). Together the two stations had in 1900 an average daily traffic of 4,800 wagons. In Genoa, with 7·7 kilometres (4·78 miles) of quays, and 48 kilometres (30 miles) of railway thereon, the daily traffic in 1900 averaged 2,100 wagons, nearly equal to that of Mannheim, but with less than half as much railway accommodation; and the latter is far harder worked than that of Antwerp. Moreover the sorting-yard for Genoa, with room for 4,000 wagons, is at S. Bovo near Novi, over 50 kilometres (31 miles) distant: which necessitates a preliminary sorting on the quays, to separate wagons for Novi from those for intermediate stations. There is a small subsidiary yard at Sampierdarena; and a new sorting-yard is now being laid out at Campasso, about 2·5 kilometres (1·55 mile) from Genoa quays.

Conclusion.—At Genoa much has been done in a few years, and much yet remains to do in order that the port may not continue to be hampered by want of adequate means for dealing with the rapidly increasing traffic. Not only ought the equipment to be amplified, but the old kind of cranes hitherto used ought to be abandoned, and replaced by better appliances. Then will Genoa be enabled to cope with the new streams of traffic which her favourable geographical position assures for the future; and to sustain successfully the competition of rival ports, especially that which Germany is contemplating by extending the great Rhine navigation towards the confines of Switzerland.

A. B.

Experiments on a Rateau Low-Pressure Turbine in the Bruay Mines.

(Bulletin de la Société de l'Industrie Minérale, 1903, p. 315.)

This is a multiple-expansion turbine, with disks 88 centimetres (34·65 inches) diameter, keyed on the same horizontal shaft. These disks turn between fixed diaphragms, at whose periphery the distributors are fixed, the whole forming a set of turbines in series. The expansion of the steam takes place entirely in the

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successive distributors, in such wise that the fluid acts on the vanes of the movable disks by its momentum alone. Each movable disk rotates therefore in a medium of uniform pressure, which permits a relatively large play of from 3 to 5 millimetres (0·1 to 0·2 inch) between the vanes and the surrounding casing. The radial depth of the vanes, as well as the sections of the different distributors, increase from inlet to outlet, so as to afford an area of cross-section which increases as the pressure and density of the fluid diminish.

Two continuous-current dynamos on a three-wire circuit, are keyed on a shaft which is coupled directly to that of the turbine. These dynamos are two-pole machines, and carry also two auxiliary poles intended to effect the commutation without moving the brushes; their indicators, drum-wound and connected in series, are each capable of giving a current of 400 to 450 amperes at a tension of 250 volts. In all the experiments the steam was superheated from 40° to 50° C., in consequence of the expansion that occurs in passing from the boiler pressure to a pressure hardly equal to that of the atmosphere. The consumption of steam per kilowatt at full load is about 18 kilograms (40 lbs.) per hour at 1,600 revolutions per minute, and falls to 17 kilograms (37·5 lbs.) at 1,800 revolutions, with a vacuum of only 63 centimetres of mercury (24·8 inches). If the vacuum had reached 70 centimetres (27·5 inches), which is perfectly attainable with a good condenser, these consumptions would be less by 25 per cent., and would consequently fall to 13·5 kilograms (30 lbs.) and 12·8 kilograms (28·2 lbs.) respectively. The total efficiency, at 1,600 revolutions and full load, of the turbine and dynamo was 55 per cent., and at 1,800 revolutions 58 per cent. As the dynamo was designed not to exceed this speed, the experiments could not be pushed further, but if the efficiencies obtained are plotted as a function of the velocity, it may be estimated that at 2,400 revolutions per minute an efficiency of 64 per cent. might be obtained; and this speed has since been attained on a similar installation of larger size, supplied with high-pressure steam. Curves of efficiency at 1,600 and 1,800 revolutions per minute are shown plotted as functions of the electric horse-power at the terminals, from which it appears that the efficiency is already very high at one-third full load, and remains almost unchanged above half full load. A curve of steam consumption to a base of loads shows that the steam used when running light, but the electrical machine remaining excited, does not exceed 12 per cent. of the consumption at full load, and in other cases has been as low as 9 per cent., whereas plants driven by piston engines consume in general 20 to 25 per cent. of their total steam at full load. Finally, a curve is drawn to show beforehand the consumption per electric horse-power that may be expected from a turbine-dynamo working between atmospheric pressure at admission (1 kilogram per square centimetre absolute), and different exhaust pressures from a vacuum of 74 centimetres of mercury (29 inches) to one of 55 centimetres (21·6 inches) for total efficiencies of 0·50,

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0·55, 0·60, and 0·65 respectively. This curve illustrates the enormous importance of a perfect condenser. A curve of theoretical consumption is added for the sake of comparison.

E. H. S.

A Rolling-Mill Engine with Körting Jet-Condenser.

(Stahl und Eisen, 1903, p. 585.)

At the Nischne Saldan Works in the Ural a Körting condenser, using 1,000 tons of injection-water per hour has been adapted to a reversing rail-mill engine with very satisfactory results. The engine has three horizontal cylinders 1,100 millimetres diameter and 1,200 millimeters stroke working with steam at 8 atmospheres admission pressure and 120 to 140 revolutions per minute develops a maximum of about 5,000 HP. which is only required for about 8 seconds at the entry of the bloom, the final pass taking only about one-fourth of the full power. Each cylinder has a separate exhaust pipe leading to a junction piece and a closed vertical receiver 2 metres in diameter and 11 metres high, with an internal barometric tube of 1 metre diameter leading to the jet-condensing arrangement. This is 4·7 metres in total height. The circular aspirating nozzles, 14 in number, convey a height of about 2½ metres. The tank supplying the condensing water-jet is placed overhead, measuring 4 metres in height, 2·7 metres broad, and 5·2 metres long. When running slowly a vacuum of 0·9 atmosphere is obtained, which, with faster running and higher steam admission, falls to about 0·5 atmosphere, a result partly due to contractions in the steam passages.

In rolling rails from blooms 130 by 140 millimetres, which is effected in seven passes, the maximum work measured on the shaft of the rolling mill is 4,500 HP., and the minimum in the last groove of the finishing rolls 1,366 HP., of which 659 HP., or about 50 per cent., is obtained from the condenser, the elongation of the work during this pass being 9 per cent. At the fourth pass the work is 2,383 HP., 536 HP., or 22½ per cent., from the condenser, and the elongation 32 per cent., while at the third the corresponding figures are 4,499 HP. for the engine, 710 HP., or 15·3 per cent., from the condenser, and the elongation 46 per cent. The weight of the bloom is 1,160 kilograms, and the power expended in the work per kilogram of metal 9 HP. in the third, 8·2 HP. in the fourth, and 13 HP. in the last pass.

H. B.

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Swiss Steam-Engines for the Metropolitan Electric Supply Company of London.[1]

(Schweizerische Bauzeitung, vol. xl. p. 257. Figs.)

Last year the Metropolitan Electric Supply Co. ordered for their Willesden central station two large dynamos direct driven by vertical steam-engines, the dynamos to be built by Messrs. Kolben and Co. of Prague, and each to develop 3,000 to 3,500 kilowatts, and the engines to be constructed by Messrs. Sulzer Bros., of Winterthur, Switzerland. These two dynamos are intended to work in parallel with five American dynamos, each of 1,500 kilowatts capacity, already in use. The article describes both dynamos and engines, but the following data relate to the engines only, of which a number of illustrations are given. No explanation of the reason for placing the orders abroad is given.

The engines are of the vertical marine compound type, with one high-pressure cylinder 50·2 inches diameter, and two low-pressure cylinders each 70·9 inches diameter, one placed on each side of the high-pressure cylinder. Each of the three cylinders is provided with Sulzer valve motion. The engines work at 75 revolutions per minute, and the stroke is 51·2 inches.

The relative volume of the high-pressure and two low-pressure cylinders is 1 : 4, and the engines can be worked either condensing or non-condensing.

The performance of the engines with an initial steam-pressure of 154 lbs. per square inch, and with 30 per cent. and 40 per cent. cut-off in the high-pressure cylinder with saturated steam and condensation, was 4,660 and 5,380 I.HP. respectively, corresponding to 4,300 and 5,000 B.HP., or an efficiency of 92·3 per cent. and 93 per cent. The same output can be obtained when the engines are working non-condensing.

The guaranteed steam-consumption per I.HP. with an initial pressure of 154 lbs. was as follows :—

	Full Load.	Three Quarters Load.	Half Load.
Output in I.H.P.	4,660	3,500	2,330
„ kilowatts	3,000	2,250	1,500
Cut-off in high-pressure cylinder (condensing) per cent.	30	16	6
„ „ „ (non-condensing) „	41	31	22
Steam-consumption—			
Condensing lbs. per I.H.P. hour	14·2	13·2	13·0
Non-condensing „ „ „	22·0	18·8	18·3

[1] An illustrated description of these engines will be found in *The Engineer*, London, 10 and 17 April, 1903.—Sec. Inst. C.E.

E. R. D.

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Testing of Indicator-Springs. E. Roser.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 1575.)

The Author describes the methods practised for the testing of indicator springs, with special reference to those intended to be applied to steam-engines. The loading of the spring may be effected by fluid pressure produced by pumping; a loaded piston and a standard gauge being used for measurement of the pressure. Apparatus arranged on this principle generally possesses considerable friction. The loaded piston and the standard gauge only give the same reading of pressure when the piston with the superimposed weights is set revolving. For testing and calibrating the springs under working conditions the pump may be replaced by a steam-boiler. It is to be noted that in indicating engines the temperature inside the indicator is generally lower than that of the steam in the cylinder. For testing indicators by steam-pressure it is desirable that boilers specially fitted up for the purpose be employed, with means for regulating the steam-pressure and producing a vacuum when required. Such a boiler is provided in the Engineering Laboratory at the Stuttgart Technical High School, with facilities for testing six indicators simultaneously. Instead of a loaded piston the Stuttgart testing apparatus has a column of mercury, the height of which can be varied up to nearly 60 feet.

Indicator springs may also be tested by the direct application of known weights, and the Author describes and gives drawings of a number of different arrangements of apparatus. This method is cheaper and quicker than that in which steam is obtained from a specially constructed boiler, except when numbers of indicators are continually being tested, in which case the testing by steam has the advantage over the method of direct weighing.

The Author finally considers the interpretation of the steam diagram in the light of the tests and calibration of the spring, the principal point requiring attention being the variation of the scale with the different intensities of pressure.

J. G.

Worm-Gear with Three-threaded Worm. C. Bach and E. Roser.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 221.)

The particular object of the investigation undertaken by the Authors was to determine the variation of temperature of the oil in which the worm was enveloped, for varying loads and speeds of the gearing. The worm was of unhardened steel and 93·5 millimetres (3·67 inches) in external diameter, the worm-wheel of bronze and 242·6 millimetres (9·54 inches) in diameter. The

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gear was driven by belt from a dynamometer in which the work delivered was ascertained from the pressure on the teeth of one of the wheels. The output of work from the worm-wheel was measured by a brake dynamometer. During the experiments the speed of the worm was varied between 64 and 2,145 revolutions per minute, and the pressure on the teeth of the worm-wheel between 111 kilograms (244 lbs.) and 1,257 kilograms (2,771 lbs.).

The temperature of the oil attains a steady condition when the difference between it and that of the surrounding atmosphere is sufficient to lead off all the heat developed by the friction between the worm and worm-wheel. It was found that with the speed remaining constant, the maximum difference between the temperatures of the oil and external air was approximately proportional to the pressure on the teeth. If a particular temperature is set down as the highest permissible, then, with an increase in speed of running, the pressure on the teeth requires to be diminished. The pressure P is equal to the weight at the end of the brake-lever multiplied by the length of the arm and divided by the radius of the pitch circle of the worm-wheel. The Author sets $P = k\,b\,t$, b and t being the width and pitch of the teeth and k a constant. By the aid of this constant the allowable pressure on the teeth may be calculated from the maximum rise of temperature considered desirable. The proper value of k is derived from the following equations, which embody the experimental results obtained by the Authors:—

$$k = a\,(t_0 - t_1) + b$$

$$a = \frac{0{\cdot}0669}{v} + 0{\cdot}4192$$

$$b = \frac{109{\cdot}1}{v + 2{\cdot}75} - 24{\cdot}92$$

in which k is the coefficient in $P = k\,b\,t$, the pressure being in kilograms and b and t in centimetres, v is the speed in metres per second of a point on the pitch line of the worm, t_0 and t_1 are the temperatures of the oil and the air respectively.

The efficiency of the gearing during the various experiments varied from 0·65 to 0·84.

J. G.

The Wilskemp Smoke-Consumer.

(The Engineer, 8 May, 1903, p. 480.)

The additional apparatus needed in conjunction with the ordinary boiler furnace is a small gas-producer, from which the gas is taken by pipes to a combustion chamber at the rear of the bridge at the back of the grate. The combustion-chamber is formed by

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an arch of fire-brick, arranged in three courses, spaces being left between the bricks in the different courses on the hit-and-miss principle; the flames from the burning gas have thus to take a zigzag path upwards towards the furnace flue which keeps the brick arch at a high temperature. The space over the fire-brick arch is called by the inventors the regenerator, and it is claimed that, when the apparatus is used, there is not only an absence of smoke but also an appreciable economy.

Fitted to a Lancashire boiler, 7 feet diameter and 24 feet long, with 600 square feet of heating surface and 32 square feet of grate area, the producer was 3 feet 6 inches diameter and 6 feet high, with a grate surface of 2·16 square feet; the steam-supply pipe was ½ inch in diameter, and had a ⅛-inch hole at the nozzle, the air-supply pipe tapered from 3½ inches to 1½ inches. The gas-pipes leaving the producer were 3 inches diameter, with two branch pipes 2 inches diameter from it to each furnace. A hinged door, hung under the bridge and moved by a rod brought out near the fire-door, regulates the amount of air to the combustion chamber.

A. W. B.

Lessons from Boiler-Explosions. C. Bach.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 160.)

The first instance considered is that of a flat-ended Lancashire type of boiler, the back plate of which was partly blown out, the gusset stays being torn away. In testing such a boiler under hydraulic pressure the flues afford considerable support to the plates forming the ends. The case is entirely different in actual working conditions; the flues, being directly exposed to the flame, expand more than the boiler shell and, instead of assisting the end plates, in reality put more load on them. The Author has had evidence of this action in various boilers when the rivets connecting the flues with the end plates have been cut out; the holes in the flue have been elongated inwards, the greatest amount of shift, in the Author's experience, having been 12 millimetres (0·47 inch).

The second explosion was that of a boiler consisting of two lower boilers with corrugated furnace tubes, and an upper boiler, the lower half of which had a number of smoke tubes. The end plates of this upper boiler were dished, the convexity facing forward in both cases, so that the back plate was exposed to a buckling pressure. The smoke tubes formed a considerable addition to the strength of this back plate in its lower half, but the buckling load of the unstrengthened plate, being only 2·5 atmospheres (35·5 lbs.) above the test pressure—which was equal to the working pressure of 12 atmospheres increased by 5 atmospheres—the upper half must be considered as having been too weak from the beginning. It should have had a factor of safety

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for buckling of about 2. A further fault in the design was riveting the dished end plate with the convexity inwards. The flange being on the outside, so that machine riveting of the end plate was possible, makes no difference to the Author's opinion. In this boiler also the relatively great expansion of the smoke tubes was an undoubted source of weakness, and the Author recommends that all flues and smoke-tubes should be fixed to the tube-plates in a heated condition. The final case mentioned by the Author is where the flat tube-plate of a vertical boiler was forced outwards. This accident occasioned the issuing of a special government regulation recommending the provision of special stay tubes for all flat tube plates. The Author does not agree with the terms of the regulation, and gives his reasons for taking up this position. Several drawings of the exploded boilers occur throughout the text.

J. G.

Strength of Boilers Lessened by Manhole Openings. C. BACH.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 25.)

The Author's attention was drawn to this subject through the explosion of a boiler. The fractures had originated at the edge of the manhole, which had been formed by simple cutting away of the plate without any strengthening whatever. Test pieces cut from the broken wrought-iron shell plates gave the following results: tensile strength from 2,678 to 2,906 kilograms per square centimetre (17 to 18½ tons per square inch), ultimate extension 1·1 per cent. to 1·4 per cent. To elucidate the subject, the Author had two cylindrical vessels made of cast iron, one with a manhole cut and closed as in the boiler that had exploded, and the other with no manhole. Both vessels were tested to destruction. The final conclusion from the experiment was that the strength of the vessel without the manhole was greater than that with the manhole in the ratio of 3·27 to 1. The vessels were 5 feet long by 2 feet in diameter, and the manhole was of elliptical shape, 11½ inches by 14½ inches, with the major axis in the direction of the length of the vessel. The greatest length of manholes should be in the direction of the circumference of boilers, as the stress on the shell is much less parallel to the axis of the boiler than at right angles thereto. The two chief reasons for the weakening induced by the presence of manholes are the concentration of tensile stress at the edges of the hole and the bending stresses occasioned by the method used to close the opening.

J. G.

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Aluminium Ores in Italy.

(Giornale del Genio civile, Rome, September, 1902, p. 460.)

Of bauxite—ferruginous hydrate of alumina—which is the ore mostly employed for the production of aluminium, no deposits were known in Italy until recently. But alumina occurs in other Italian ores, which under more favourable conditions were formerly worked for the iron they contained. An ore from the Rocca di Mezzo district, analysed in March 1899 in the laboratory of the Terni steel-works, was found to contain barely 25 per cent. of peroxide of iron, equivalent to 17½ per cent. of metallic iron, and was thus too poor for steel making; but in alumina it was rich, yielding 56 per cent., equivalent to nearly 30 per cent. of aluminium. Two other samples of the same ore were obtained in the hills of Lecce nei Marsi during the geological survey in 1900; one contained 58 per cent., and the other, from the western side of Turchio hill, 47 per cent. of alumina. Lignite also having been found not far from the ore in the Abruzzo, grants were made at the close of 1900 for working peat, lignite, asphalt, iron ore, and any other minerals in the neighbourhood of Avezzano, particularly round the basin of the drained lake Fucino, where the beds of aluminiferous iron ores lie at a height of about 1,200 metres, (say 4,000 feet).

Another ore, which presumably could be utilized for the production of aluminium, is *leucite*—anhydrous silicate of alumina and potash. It is characteristic of the volcanic region near Rome; and is found generally throughout the tufa or pozzolana, in varying proportions and either amorphous or crystalline. In 1901 permission was sought to work a bed of volcanic conglomerate, which had been cut into in making the railway up to Frascati, and crops out at a little distance from the town with a face 8 to 10 metres (26 to 33 feet) high; the overlying burden is about 1 metre (3¼ feet) of fine ash, covered with tillable soil. An analysis showed 55 per cent. silicon, 23½ per cent. alumina, and 21½ per cent. potash: all three of which could be utilized profitably and without waste. At present however the desired permission has been refused on legal and other grounds, which are set forth in detail. A. B.

Filling Mine-Workings with Water-Carried Material.

CARL ČIŽEK.

(Oesterreichische Zeitschift für Berg- und Hüttenwesen, 1903, p. 293.)

The method of filling exhausted coal-workings with waste material, flushed down by water from the surface, which was introduced at Myslowitz in Silesia in 1901, has been adapted to the working of a seam 4 metres thick at Polnisch-Ostrau, in a

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mine where the growth of the population has necessitated the locking up of about 6¼ acres, containing more than a 1,000,000 tons of coal, in safety pillars for the support of the houses and other buildings that have accumulated about the shafts. The seam, which lies at a low angle of inclination, is opened out in broad pillars, which are subsequently divided through by cross driving, and the final removal is effected by forming chambers 8 metres long in the direction of the strike, which are enclosed on the free sides by dams formed of a double layer of planks with an intermediate packing of brushwood, the space left by the removal of the coal being immediately filled by sand and other waste material mixed with water, and brought in through an open launder from a lateral drift. The packing material is principally loamy sand from a hill adjoining the shafts, which together with the ashes and waste of a large coking-plant, is trammed to a conical feeding-hopper, placed in a shallow pit adjoining the upcast shaft, and communicating with it by a lateral drift. A screen with bars 2¼ inches apart at the bottom of the hopper keeps back large stones. The flushing water is supplied from underground by a pumping-engine, raising 3 tons per minute from a depth of 220 metres to a storage-reservoir on the hill, whence it passes by 145-millimetre gas-pipes to the distributing funnel, and, mixing with the waste, carries it down into the shaft and levels by a steel pipe of the same size, which is 6½ millimetres thick in the shaft, but is thickened to 10 millimetres in the bends in the workings, where the scouring action is a cause of increased wear, the final distribution being effected by open launders, which can be shifted to deliver at any required angle. These are so arranged that the material introduced has no greater distance than 3½ metres to flow from the point of introduction before coming to rest. As soon as the water has drained off the surface of the deposit it is perfectly firm, and can be walked upon. The proportion of water required to packing material is as 1 to 1 when the latter is of a dry or sandy character, but when loamy or containing clay it must be increased to nearly 2 to 1. With the available water supply, from 60 to 70 cubic metres of packing may be introduced per hour, at which rate a chamber containing about 450 tons of coal might be completely filled in about six working days.

H. B.

A New Method of Removing Furnace Obstructions.

D. WEEREN.

(Stahl und Eisen, 1903, p. 508.)

This describes a method of removing scaffolds in blast furnaces, and the division of unmanageably heavy metallic masses by fusion, which has been introduced by Dr. E. Menne at the Creuzthal blast furnaces near Siegen. The apparatus is an oxyhydrogen blow-pipe

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formed of the concentric tubes, an outer one of 20 millimetres connected with the coal-gas supply and an inner one of 5 millimetres, centred by four set screws supplying the oxygen. The tube, which may be made up to several metres in length, is protected at the burner end by a refractory casing made of compressed carbon, coke, graphite, gas-retort carbon, magnesite, or carborundum, or a hollow copper nozzle, provided with an active cooling water, circulation may be used. Both the oxygen and the coal-gas are supplied in steel cylinders at a pressure of about 100 atmospheres, which is lowered for use to 30 atmospheres by reducing valves. As an example of the use of the method the operation of burning a hole through a block of iron 16 inches thick is given. A point in the mass is brought by the oxyhydrogen flame to a very high temperature; it need only be small, but must be nearly at a white heat. The supply of oxygen is then slowly increased, taking care to reduce it if there is any sign of diminution of the heat at the spot attacked. When the iron has been brought to the point of ignition, combustion goes on very rapidly, and the coal-gas may be partially or even entirely cut off, the pressure of the oxygen being increased to 20 or 30 atmospheres. The heat developed by the burning iron melts the metal in the immediate neighbourhood, and the contents of the hole are shot out like a fountain, so that in 1½ minutes to 3 minutes a hole 4 inches in diameter may be bored through the cold metal, and with glowing masses the time is considerably shorter. This is the more remarkable, as from the sudden expansion of the oxygen it is reduced at the point of the jet to 10 degrees below zero C. The method has been successfully applied to the removal of obstructions in the hearths and boshes of blast furnaces, and the couplings of rolling mills. In the latter case a cast-steel collar, 16 inches long and 8 inches thick, on a coupling shaft, which could not be removed after two days' trial with the assistance of a charcoal fire, was scored with a deep groove, and removed within half an hour without injury to the shaft by the blowpipe. The remarkable effects obtained by the arrangement are due to the local concentration of the heat consequent on the low conductivity or thermal capacity of iron. This affords a method of clearing out blast or slag twyers that have become blocked with iron.

The thermal value of iron compared to that of hydrogen is as 1,650 to 28,780, or 1 to 17·4, but their volumes for equal weights are as 1 to 87,240, or for equal volumes consumed, iron develops 5,014 times the heat of hydrogen, and this heat is so rapidly developed that there is no time for its dissipation by conductivity through the metal, which therefore remains cold around the melted area. Copper and bronze, on the other hand, are entirely unaffected, as the heat applied is rapidly disseminated through the mass.

H. B.

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The Thermal Occurrences in Gas-producers. F. LÜRMANN.

(Stahl und Eisen, 1903, p. 433.)

This is a detailed arithmetical study of the thermal changes involved in the production of fuel gas from bituminous coal and the calorific value of the product under different conditions of oxidation, *i.e.*, with air alone, and with steam or blast-furnace gas under two conditions, the first being in conjunction with air, and the second with air enriched to 50 per cent. of oxygen by the Linde process. The numerical results for each of these different conditions have been computed for different temperatures in the oxidizing agent between 100° C. and 1,000° C., and are contained in a series of Tables, which are too voluminous for reproduction. The most noticeable results of the calculations are given in the following abstract :—

	Air 23 Per Cent. Oxygen and—				Air 50 Per Cent. Oxygen and—			
	Steam.		Blast-Furnace Gas.		Steam.		Blast-Furnace Gas.	
	100°	1,000°	100°	1,000°	100°	1,000°	100°	1,000°
Steam or gas, per kilogram bituminous coal	0·336	0·537	0·568	1·508	0·428	0·544	0·968	1·542
Weight of coal per kilogram of steam or gas injected . .	2·980	1·862	1·761	0·663	2·338	1·838	1·068	0·649
Heat obtainable per kilogram of coal used . . . Cals.	5935	6610	6080	7173	6566	7010	6508	7214
Bituminous coal consumed per 1.000 . . . . . Cals.	0·169	0·151	0·164	0·139	0·152	0·143	0·154	0·139
Thermal value of gas per cubic metre . . . Cals.	1667	1979	1567	1634	2459	2549	2244	2147
Theoretical flame temperature °C.	2136	2294	2118	2182	2454	2491	2436	2419

The theroetical maximum temperatures are computed on the old method, or without taking into consideration the increase in the specific heat of water vapour and carbon dioxide at high temperatures.

The use of blast-furnace gas instead of steam in the producer is suggested as a more direct method of utilizing the heat in steel works having producers where the steam injection is derived from boilers fired with blast furnace gas, as the steam in such cases being mostly delivered through long conduits arrives in a very wet condition, and also as the dust would be retained in the producer slag the expensive cleaning plant now considered necessary would not be required. Air enriched to 50 per cent. of oxygen by Linde's method may, according to Pictet, be produced

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with steam power for 1·7*d.* per thousand cubic feet, 650 HP. being sufficient to produce 87,000 cubic metres (3,100,000 cubic feet) per day, and such air might be specially useful in heating up steel for small open-hearth castings. When applied with steam in the producer under the condition given in column 6 of the above Table, the thermal value of the product equals that of water-gas, and with blast-furnace gas the result is nearly as good; and such gas might be applied for lighting with incandescent burners instead of following the more circuitous method of first converting it into electricity by means of gas-engines and dynamos.

H. B.

Method of Measuring Underground-water Velocity. SLICHTER.

(Journal für Gasbeleuchtung, 1903, p. 230.)

As the motion of underground water is being more studied, it becomes increasingly important to have ready means of determining its velocity. In the memoir quoted, the Author describes a simple and accurate method of determining this.

Two bore-holes or wells are sunk, and the bore-pipes (which are metallic) are electrically connected. An ammeter is included in the circuit, the earth forming the return. A second circuit is also connected up to the ammeter. This is formed essentially by the bore-pipe of the lower well, the water in this well, and an insulated wire hanging down into the water.

The ammeter thus measures both the resistance of the earth circuit between the two wells and that of the water in the second well.

An electrolyte is now introduced into the first well. Repeated experiments show that Ammonium Chloride (Sal ammoniac) is the best for this purpose, as it shows little tendency to diffuse, and has a very fair conductivity.

As the salt is carried towards the second well, the earth-resistance decreases. This is shown by a slow motion of the ammeter needle; but when it reaches the second well the resistance of the second circuit is suddenly immensely diminished, and this is shown by a large throw of the ammeter needle.

K. T.

Measurement of Leakage in Water-Mains. W. BUCERIUS.

(Journal für Gasbeleuchtung, 1903, p. 256, 11.)

At any convenient point in the main a by-pass is attached, and during the hours of minimum consumption the water is forced to pass through this by shutting down a valve in the main.

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In this "shunt" circuit is a conical length of pipe. The pressure at the two ends is therefore different, and this pressure difference is measured by a mercury manometer. By an ingenious non-return valve, the manometer may be made to register the minimum pressure difference. This pressure difference is directly related to the rate of flow, and the latter can be obtained accordingly. This is taken as the minimum or leakage flow.

K. T.

Estimating the Wall-thickness of Rammed-concrete Mains.

G. RAMSISCH.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1903, p. 106.)

The formula recommended for estimating the strain at the crown of the pipe is $\frac{k}{p} = \pm \frac{3}{2}\left(\frac{r}{h}\right)^2$, wherein k represents the tension on the extreme outer and inner faces per unit surface, p the load, r the radius to the centre of the pipe wall, and h the thickness of the latter. The tension expressed by the plus sign applies to the inner surface, and the pressure indicated by the minus sign to the outer surface at the crown of the pipe. Then the radius of the internal circumference of the pipe being expressed by r°, and since $\frac{r^\circ}{h} = \frac{r}{h} - \frac{1}{2}$, the formula for ascertaining the thickness of the pipe walls is worked out by the Author as: $h = \dfrac{r^\circ}{\sqrt{\frac{2}{3}\frac{k}{p}} - 0{\cdot}5}$.

C. S.

Laying 6-foot Concrete-Jacketed Riveted Steel Pipes under the Hackensack and Passaic Rivers.

(Engineering News, 12 March, 1903, p. 232.)

A steel pipe, 6 feet in diameter and forming a part of the new water-supply for Jersey City, N.J., has recently been laid beneath the Hackensack River, near Garfield, and beneath the Passaic River at Lyndhurst, N.J. The pipe was put together on one shore, piece by piece, as it was hauled across under the water. The main across the first river is laid in 45 feet of water, at the second river the depth of water is 28 feet, the length of the crossing being 575 feet. The pipes were built up of steel plates $\frac{11}{16}$ inch thick, with single-riveted circular and double-riveted longitudinal joints, constructed in sections 32 feet long, which were connected together on the shore.

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To protect the pipe from outside pressure and prevent it from floating, concrete cylinders 6 inches thick were slipped over the pipe, the space between the inside of the cylinders and the pipe being grouted up. A. W. B.

Sewage Purification by Means of Intermittent Irrigation.

G. Oesten.

(Gesundheits-Ingenieur, 31 May, 1903, p. 242.)

The problem of the purification of town sewage is regarded as a twofold one—first, the removal of the fouled water in such a way as to avoid all objections from the sanitary point of view, and, secondly, the extraction from it of the valuable manurial constituents in such a form as to be most serviceable for the production of new organisms; while a third condition may be added, namely, that this should be done with the smallest expense and on the least possible extent of ground. The Author states that the modern tendency is at all hazards to satisfy this third set of conditions. The long-established practice of agricultural irrigation is being pushed into the background, though the results obtained thereby are in the main satisfactory. That system is, from the present aspect, too costly, both in regard to area, management and working expenses. Owing to this fact efforts are continually being made to obtain equally good results at a less outlay. This has led in the past to the introduction of the various precipitation processes, none of which, however, fully satisfy the conditions, and more recently to the adoption of the so-called biological or oxidation processes; but these last, while they fulfil the first of the requirements, are conspicuously inefficient as respects the recovery of the manurial ingredients. The Author discusses the main principles on which the biological treatment of sewage is founded, and shows that a highly porous mass must be filled and emptied alternately with air and sewage water. By reference to diagrams, the best method of obtaining parallel results by means of a system of intermittent irrigation on a restricted area is described. In order to carry out the plan efficiently, arrangements must be made for giving rest to certain plots for a long period (not less than a year), during which time the land must be used for agriculture. Reference is further made to the possibility of utilizing the effluent or subsoil drainage-water, which, although clear and colourless, has still a certain proportion of organic matters and salts in solution. This water may be stored up in ponds for breeding fish, and the effluent will speedily become available for this purpose, owing to the luxuriant vegetation and the abundant supply of minute animalculæ which it is capable of producing.

G. R. R.

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The Conflict with Malaria. Robert Koch.

(Zeitschrift für Hygiene, vol. xliii., 1903, p. 1.)

It is stated that when, 10 years ago, the Author was face to face with the combat with cholera, it was recognised that the preventive measures must be directed against the germs which could in every case be demonstrated by bacteriology to be the active agents in the spread of the disease. When he had time to turn his attention to the diagnosis of malaria, he found in a similar way that the blood was infected with a parasitic organism easily destroyed by quinine, which, although it was wholly different from that of cholera, might be attacked and dealt with on a similar principle; and, by means of his experiments at New Guinea, he satisfied himself not only that it was possible to destroy the malarial parasite in human blood, much in the same manner as in the case of the cholera germ; but also that the active agent of malarial diseases was capable of existing only in man and in certain insects of the gnat tribe, and was not to be found in any other organism. This rendered it possible to undertake the necessary preventive measures which have been adopted with complete success. Accounts are then given of the conflicts with malaria at Brioni (Istria) by Prof. P. Frosch, and at Puntacroce by Dr. Bludau. A report is printed of the malaria-expedition to German South West Africa by Dr. Vagedes, and descriptions follow of the conflicts with this disease at Daressalam by Dr. Ollwig, and in the Tuscan Maremma by Dr. B. Gosio. This last investigator declares that only time and a sufficient supply of quinine are needed to stamp out the disease. Dr. E. Martini treats of the precautions taken to avert an outbreak of malaria at Wilhelmshaven, and Mr. Dönitz gives an account of the various species of the anopheles which serve to spread the disease in the different countries where the question has been actively studied. All these essays are illustrated with maps, photographs and diagrams.

G. R. R.

An Explosive outbreak of Typhoid Fever.

Bachmann and Kattein.

(Gesundheits-Ingenieur, 1903, p. 121.)

About 5 miles before reaching Hamburg the River Elbe divides into two arms, the Northern and Southern Elbe, which reunite below the City, enclosing thus the very considerable island of Wilhelmsburg, some 10 square miles in area, of which a plan and a description are given. A peculiar feature of this island is the extent to which it is traversed in all directions by shallow water-courses, filled with abundant marsh vegetation. The rural

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population inhabiting this area are for the most part housed under very insanitary conditions, which are herein described. Among the 20,000 inhabitants, diarrhœa and typhoid fever are usually prevalent every year during the summer months, but in July, 1902, in the Reiherstieg district, a violent outbreak of typhoid fever, which involved forty-four families living in two double blocks of dwellings, made its appearance and occasioned in all sixty-one cases of illness, of which an account is given. The water-supply was at first regarded as free from suspicion, as the water for all the forty-four dwellings was drawn from one tube-well of good construction, some 50 feet in depth, but the water was found on examination by the Hygienic Institution of Göttingen to be infected. By reference to diagrams it is shown that, owing to the imperfect construction of the joint of a pump by means of which the water was drawn from this tube-well, it had become possible for a leakage to take place of very filthy water from a drain which ran close by, and by this means the water had become so polluted that no less than 480,000 germs per cubic centimetre were found in the pump-shaft. After thorough disinfection the numbers sank to very insignificant proportions, and indicated that the water of the well was in itself of good quality. It was not possible to demonstrate, by actual cultivation-tests, the presence of the typhoid-fever bacillus, but the condition of the water before and after the discovery of the defective joint, left no doubt that the outbreak was attributable to this cause.

G. R. R.

Dangers of Disinfection by means of Corrosive Sublimate.

Dr. E. Bertarelli.

(Zeitschrift für Hygiene, vol. xlii., 1903, p. 553.)

An account is given of the opinions which, at various times, since Guttmann and Merke first called attention to the subject, have been expressed with respect to the possible dangers to health that might arise from the metallic mercury due to the decomposition of corrosive sublimate (mercuric chloride) when employed in solution for the purposes of disinfection. Among others, the views of Esmarch, Mörner[1] and Sjöqwist are cited and the observations of Krupin and Bordoni-Uffreduzzi on the health of members of the staff engaged in the work of disinfection, where corrosive sublimate was in use, are discussed. In the presence of some conflict of opinions, the Author has undertaken, in the course of 1900 and 1901, a series of investigations into this subject at Turin, where an excellent opportunity was afforded for the enquiry, as it has been the practice to employ for many years past a very concentrated solution of the mercurial salt (10 per mille) for disinfecting purposes.

[1] Minutes of Proceedings Inst. C E., vol. cxx. p. 404.

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His experiments included both persons who inhabited the disinfected dwellings and those who were habitually engaged in the work of disinfection. The urine and the excreta were systematically collected and tested, and small special chambers of wood and cement were constructed for observations upon animals. The walls of these chambers were frequently well washed with the solution, and live mice were then placed in them with such arrangements for feeding as to avoid all possibilities of direct contact of the food with the walls and floors. A full account is given of the methods of testing and of the extent and duration of the experiments. The Author likewise examined the air-currents passing through chambers in which the corrosive sublimate had previously been used as spray, but in no case was it possible to demonstrate the faintest traces of sublimate in the water employed for washing the air. As the general result of his investigations, he states that this substance may be employed with the utmost confidence for disinfection, and that, with proper precautions, such as are always enjoined, even the officials, who are constantly engaged in the work, run no risks of mercurial poisoning.

G. R. R.

The Disinfection of Dwellings. KISTER and MATTHES.

(Gesundheits-Ingenieur, 10 March, 1903, p. 105.)

Attention is directed to the increasing use of formalin, which, whether employed as vapour or spray, is gradually taking a very prominent place among the disinfectants available for use in dwelling-houses. In those cases in which it becomes necessary to undertake a very searching and complete disinfection, the use of a fluid medium, with which all exposed surfaces can be saturated, and which can be forced into all chinks and crevices, is greatly to be preferred, and hence, in addition to treatment with vapour or solution of formic aldehyde, some mechanical process of scouring with hard brushes, or rubbing down with bread, is resorted to. In the case of floors and painted surfaces, the employment of abundant scrubbing with soft soap and dilute carbolic acid is also needful. As a valuable aid to internal disinfection, the Authors explain the construction and use of the portable apparatus invented by Mr. Zorn, and they give the results of certain practical tests carried out in two of the rooms of the Hygienic Institute of Hamburg, one of which was treated in the ordinary way, and one of which was disinfected by means of the above apparatus. The test-substances employed were in each case as follows:—Staphylococcus pyogenes aureus, bacterium coli, bacillus diphtheriæ, tuberculous sputum, and spores of highly resistant potato-bacillus. The rooms were of nearly equal size, and while the one dealt with on the old system needed the work of three men for 2 hours and 35 minutes, the disinfection of the other room by means of the new apparatus took

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the same staff only 25 minutes, and involved the use of a smaller quantity of carbolic acid solution. By means of diagrams, the mode of employing the spray apparatus is explained, and the results of the process in each room are set forth in tables. In the former case 87·5 per cent. of the germs were destroyed, and in the latter 88·2 per cent., but the saving in time was very considerable. In neither instance was the disinfection perfect, and some later experiments herein described gave very similar results.

G. R. R.

Uniform Distribution of Heat in Rooms. Nussbaum.

(Zeitschrift für Architeckten- und Ingenieur-Vereins, 1903, p. 154.)]

The comfort of a room requires that the difference of temperature at the level of the head and near the floor shall be insignificant, and to attain this result the difference at the ceiling and floor must not be greater than 6° or 7° F. The system of heating the floor appears to be adapted only to cases in which cost is of no particular consequence. Thicker walls and smaller windows are impracticable, and the lining of the interior with non-conducting substances is expensive. The size of windows, moreover, demands other methods. The air descending from the ceiling has its temperature rapidly lowered in contact with the glass, even when there are double windows, and spreading itself over the floor, reduces the temperature there in a way which is well understood. To prevent this a space is left in the window-breast, into which the descending current of cold air passes through slits in the sill, and from which it is discharged through a ventilator into the open air, or by aspiration along a pipe connected with the chimney. Better still, when hot pipes are used, the cold air is warmed by passing round a hot coil in the window recess, and thereby caused to rise again.

The Author dwells on the importance of constructing the floors and ceilings of non-conducting materials, when the rooms above and below are unheated; and, on the other hand, of giving every facility for the transference of heat from the ceiling of one room to the floor above when both are heated.

Prof. Esmarch,[1] by proceeding in the manner indicated, has shown that inequalities in temperature may be reduced to insignificant proportions. In his own study he found that, with the exception of the low temperature next the window and the high temperature immediately over the coil, the ten thermometers placed in various parts of his room scarcely ever differed more than 3° or 4° F.

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[1] Gesundheits-Ingenieur, 1901, p. 285.

E. H. S.

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On the Relative Value of Illuminants.

(Journal für Gasbeleuchtung, 1903, pp. 261 *et seq.*)

The article contains the reports of different experts on the relative values of different illuminants in lighting large spaces. The subject is treated more particularly from the hygienic and physiological point of view.

After stating the requirements for ideal illumination, the reports proceed to split up illumination into two classes:—

1. Direct illumination, in which the light falls directly on the object or space to be illuminated.

2. Indirect illumination in which the light is first diffused by reflection.

The Welsbach light, the electric arc and the electric incandescent light are the only illuminants considered. Several experiments are quoted, and the results arrived at are as follows, arranged in order of merit:—

(1) Indirect illumination by Welsbach light is generally best. In rooms not less than 13 feet high, mixed direct and indirect illumination is to be preferred. Otherwise the light should be thrown on to the ceiling, and thence reflected by means of metallic reflectors or enamel plates.

(2) Arc-lamps illuminating indirectly by means of large reflectors are nearly as good; in fact, for rooms of more than 16 feet height they are preferable to Welsbach burners. One 10-ampere lamp per 50 square yards of floor space is required.

(3) Where partial illumination only is required Welsbach lights are useful. They should then be furnished with inverted globes for throwing the light upwards.

(4) In (3) incandescent electric light may also be used; but it is more expensive and radiates out more heat—a point on which considerable emphasis is laid in the report.

K. T.

"*Auto-Carburisation*" *with Water-gas.* H. Dicke.

(Journal für Gasbeleuchtung, 1903, p. 411.)

The article deals with a new method of mixing water-gas with ordinary coal-gas. The results—as given in the Paper—indicate that considerable chemical changes take place when mixture is effected by this process.

Two proportions of admixture are employed: one part of water-gas to two parts of coal-gas (50 per cent.), and equal parts of the two (100 per cent.). The former strength is now regularly employed at Güstrow Gas Works, and as there are no practical objections to so strong a mixture, the 100 per cent. proportion has

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also been tried experimentally, and with most satisfactory results. The figures show that the total quantity of carbohydrates present in the mixed gas prepared by "Auto-carburisation" is greater than that of the components. The calorific value is likewise in excess of that of the components, taken separately. This leads to the important result that the addition of water-gas in large quantities by this process is actually beneficial. For ordinary lighting purposes, of course, benzol has to be added. When the mixed gas is used for Welsbach illumination, its use effects a saving of 75 per cent. of gas. This is due to the higher temperature attained. All these points are very clearly set out in a series of tables, and the Author concludes by working out the cost, etc., of an installation to yield about 200,000,000 c.f. of gas per annum with a minimum heat-value of 4,000 units per cubic foot.

K. T.

Method of Detecting Leakage in Gas Mains. E. RATTIER.

(Journal des Usines à Gaz, 1903, p. 86.)

In order to detect leakage in the branches of the mains, the Author uses a double pipe, somewhat resembling a section through a cylinder and its piston-valve. The smaller or indicator tube is perforated on its lower side with small $\frac{1}{8}$ inch holes, averaging 8 inches apart.

The pipe is laid on a board, and a space is thus left under the smaller tube. Escaping gas will thus enter it through the perforations. The indicator tube terminates at some convenient point, and here the leakage is readily detected by means of gold palladium test-papers.

The Author appears to have used this method with considerable success in France. He claims that it is a highly sensitive test, and that the extra cost of lead is small when the pipes are cast as twin-tubes.

K. T.

Efficiency of Metallic Arcs. H. ZEIDLER.

(Journal für Gasbeleuchtung, 1903, p. 331.)

The Author gives the results of a large series of experiments on the efficiency of carbons of which the "soft core" has been impregnated—presumably with metallic salts.

Two kinds of lamps were experimented with. The first was the ordinary type, in which the carbons lie in the same vertical line; in the second type the carbons both entered the globe on the upper side and converged to a point, the angle between them varying from 12 degrees to 90 degrees. These will be respectively spoken

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of as the "ordinary" and "special" lamps. In both cases experiments were made both with direct and alternating currents.

The practical construction of the "special" lamps is explained, special stress being laid on the use of a Chamotte economiser. This prevents the undue wearing away of the positive carbon, and is of fundamental importance in these "special" lamps. Unfortunately, very slender carbon rods—about ¼ inch diameter—must be used with these arcs in order to give a steady light. This means a reduced life for the carbons, and to prevent the necessity of too frequent inspection, the E. A. G. now manufacture lamps with the carbons in duplicate. This gives a life of 13-16 hours.

In the results quoted, the measurements are made as follows:

Watts per candle.—The watts are measured thus: if we have a 200-volt circuit, and our lamp takes 9 amperes, the total P. D. across the lamp terminals is only 34–45 volts, but the energy is taken as $9 \times 200 = 1{,}800$ watts, and this is the quantity which is used as a basis of calculation. Had 2–5 lamps been included, the energy used would still have been the same, whereas the candle-power would have been increased 2–5 fold.

The candle-power is measured through the opal globe. It will thus be seen that practical conditions are nearly realised.

With 5 lamps in series in this circuit, the "special" metallic arc showed a consumption of 0·3 watts per candle for direct current.
The ordinary metallic arc 0·5 „ „ „ „
„ „ non- „ „ 0·85 „ „ „ „

In alternating currents, the figures for the metallic arc are nearly the same, whilst those for the non-metallic arc rise to 1·3 watts per candle.

Another Table gives the relative illuminating powers at 5 and 10 yards. The metallic arc appears to give about 3½ times the light of the ordinary arc for the same consumption of energy.

K. T.

Extension of the Schaffhausen Electricity Works and Electric Street Railway.

(Schweizerische Bauzeitung, 1903, vol. xl. p. 281. 8 Figs.)

In 1861, the installation of the first water-power plant was begun at Schaffhausen and completed in 1866; it consisted of three turbines, together developing 760 HP. Owing to the great demand for power, a second installation of five turbines was put down in 1887, two of these are used for producing direct current for the Schaffhausen spinning works, and two others for producing alternating current for the lighting of Schaffhausen. In 1898 it was decided to revise the whole plant and supersede the rope transmission by electrical transmission, and construct an electric tramway from Schaffhausen to Neuhausen. The turbines were

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obtained from Messrs. Rieter and Co. and Escher Wyss and Co., the cars from the Swiss Engineering Works, Neuhausen, and the electrical part of the work from the Maschinenfabrik Oerlikon. Polyphase current was selected for the power-plant, and direct current for the tramways, and the alterations are now completed. The lower station upon the river was fitted with one 350-HP. hydro-electric set for the production of polyphase current, and two polyphase-direct rotary converters for the tramway service. The turbine is of the Jonval type, running at 60 revolutions per minute, and drives a generator which runs at 167 revolutions per minute, and develops 210 kilowatts, at 2,000 volts and 50 periods as a monophase alternator, and 300 kilowatts as a polyphase machine. Each of the two rotary converters delivers 182 amperes at 550 volts; there is also a secondary battery of 276 cells with a capacity of 165 ampere-hours.

The upper generating-station contains three turbines, one of the Jonval type by J. J. Rieter and Co., and the two others of the Francis type by Escher Wyss and Co.; each develops 350 HP. at 60 revolutions per minute. These drive one polyphase generator, giving 400 volts at 51 periods and 170 revolutions per minute, and also two other machines, each developing 2,000 volts at 50 periods; the efficiency of the latter is 92 per cent. at full load.

The cables are carried through stoneware conduits into the town, where there are nine high-pressure motors using 313 HP., and 28 low-pressure motors using 318 HP. together; also the three town pumping-stations are driven by electric power.

Three tramway lines are worked from the water-power stations, a pressure of 550 volts being employed. The original article contains detailed descriptions of the various machines and apparatus with a number of illustrations.

E. R. D.

Electric Transport of Coal at Haarlem.

(Journal für Gasbeleuchtung, 1903, p. 189.)

The article describes the plant recently erected at Haarlem for the more rapid transference of coal from lighters to the gas-works. The machinery, which was erected by the Brown Hoisting Co., Cleveland, U.S.A., is designed to deal mechanically with the coal from the time it leaves the lighter until it is delivered over the retorts, ready for tipping.

A grab is lowered into the barge. It raises about a ton of coal. On reaching the right elevation an automatic catch fixes it rigidly to a traveller, and this runs along an inclined railway. This is about 135 yards long, and attains a height of about 80 feet at the distant end. When the grab reaches this point, it opens automatically and drops its contents into a coal breaker. It is now weighed and delivered into tipping-wagons, which run by gravity

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to the point where they are required to deliver. Here again, a movable stop effects automatic tipping, and a counterbalance weight, which is attached to the wagon, draws it back to its original position.

A 75-HP. motor works the running gear, and the breaker requires a further 25 HP. The plant can deal with rather more than 300 tons of coal per working day of ten hours.

K. T.

Compressed-Air- and Electric Rock-drills. T. GILLER.

(Glückauf, 1902, p. 853.)

The relative merits of the various types of rock-drills have been much discussed in Germany. The question which type (electric, hydraulic or pneumatic) is best to use is merely one of power transmission, which depends upon local conditions. The Author considers that the best solution is to be found in a combination of electric-power transmission with the compressed-air percussive-drill. The combined system consists in conveying by cables to the vicinity of the working place electric energy generated at a convenient spot, and in employing it for driving a high-speed air-compressor, which is placed on a carriage that runs on rails, and is brought within 100 yards of the working place. An installation of this kind is in successful operation at the Friedrich-Wilhelm mine in Upper Silesia. The electro-motor is of 13 HP., and the two rock-drills at 6 atmospheres air-pressure require only 5 HP. The 25-HP. Meyer high speed air-compressor used measures 7¼ feet in length, 3¼ feet in height and 37½ inches in width. The Author considers that the rivalry between compressed-air and electricity as transmitters of power for rock-drills has thus been ended by this compromise between the two.

B. H. B.

Electric Charging of Gas-Retorts. P. SARRASIN.

(Journal des Usines à Gaz, 27, p. 116.)

The Author describes a new apparatus for charging gas-retorts, Electricity being the agent employed. The advantages claimed are the following:

(1) Rapidity of charging, 45 seconds being the time estimated for a single retort.

(2) Coal crushed to size before being fed into the retorts.

(3) Complete control over the quantity to be applied.

(4) Uniform distribution.

The machine resembles a planing machine, the moving bed being the feeder. The level of this can be varied at will, and there is a

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fine hand adjustment to get the exact height. A hopper supplies the coal to the feeder as required, and a pair of revolving cylinders break the coal to the required size. By varying the opening at the lower end of the hopper, the quanity and distribution of the coal can be varied.

The feeder is made in three parts: a floor, and two sides: the latter are connected by ties for the whole of their length, and may be withdrawn independently of the base.

By means of a rack and pinion motion, the feeder is run into the retort. The floor is now withdrawn, and the coal, catching against the tie rods which connect the sides, is prevented from returning with the floor and so distributes itself evenly in the retort. The sides are then withdrawn and the machine is ready to feed the next retort. Two pairs of motors are used; one pair of 1 HP., and one pair of 3 HP.

The article is illustrated by a full-page plate.

K. T.

Mercury Lamp. C. P. Steinmetz.

(Journal für Gasbeleuchtung, 1903, p. 454.)

The great luminous efficiency of vacuum tubes is well known, but such tubes are unfortunately, in general, of small practical value for lighting purposes, as they necessitate an alternating current of high frequency. As a luminous agent, mercury vapour is free from this objection. It may be excited by a direct current, and emits light at a comparatively low temperature (with gases the efficiency of the light is independent of the temperature).

The author has spent some considerable time in utilizing these properties of mercury in a practical way, and he seems to have overcome most of the practical difficulties. Chief amongst these is the method of starting the arc. A starting circuit is used, and by an ingenious arrangement of solenoid and attracted float, this is cut out when the arc "strikes" across the terminals.

The light is bluish-green in colour, varies little in intensity with great variations of P.D., and has a luminous efficiency of 30 per cent. as compared with 3 per cent. in ordinary carbon incandescent lamps.

K. T.

Strength of Struts. F. Wittenbauer.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 245.)

The Euler equation for the buckling strength of a column has reference to the particular case of a weightless beam under the action of directly opposed longitudinal forces applied at the ends. This does not cover all cases arising in practice, and the Author

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arrives at some of these by first obtaining an expression, of which Euler's equation is a particular case. He assumes a number of rods connected end to end by hinged joints; the free ends of the first and last rods are supposed to be fixed in position. The loading is applied axially at the several hinges, and there is also introduced a lateral load Q acting at M at the distance a from the fixed end A. The formula for the deflection of the point M takes the form—

$$f = Q \frac{U}{V}$$

U is a function of the lengths of the individual rods, of the axial loads, and also of the distance a. V is independent of a. Suppose now the load Q to become infinitely small, then when the deflection takes an indeterminate large value, the buckling limit is reached. The condition of this is that V becomes zero.

The first case considered is that of a strut of length l, the cross section of which varies by steps, with loads at each change of section. For a strut with two changes in the moment of inertia, the expression for the deflection is obtained from twelve simultaneous equations. A simpler case is that where there is only one change in the value of I, the moment of inertia. Suppose the load at the top is P_1, the length and I of the upper part l_1 and I_1, the length and I of the lower length l_2 and I_2. Let the load P_2 be applied at the change of section. Put $P = P_1 + P_2$. Then the relation between P, P_1 and P_2 for the buckling limit is expressed by the equation :—

$$P\, m \cot \mu + P_1\, n \cot \nu = \frac{P_2^2}{P_1 l + P_2 l_1}$$

The values of m, etc., are as follows :—

$$\mu = m\, l_1 \qquad \nu = n\, l_2$$

$$m^2 = \frac{P_1}{E\, I_1} \qquad n^2 = \frac{P_1 + P_2}{E\, I_2}$$

The ends are supposed hinged.

If the lower end is built in or fixed, and the upper end free, the condition of stability becomes—

$$\cot \mu \cot \nu = \frac{m\, I_1}{n\, I_2}$$

and if we take the case where $P_2 = o$, that is, a strut of two different cross sections loaded at the top, the equation is—

$$\cot \mu \cot \nu = \sqrt{\frac{I_1}{I_2}}$$

The stability of a long column or tower, fixed at the base and free at the top, under its own weight G alone, is determined by the equation—

$$G = 7{\cdot}837 \frac{E\, I}{l^2}.$$

J. G.

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Hydraulic Limes. H. Burchartz.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1902, p. 255.)

A definition is given of hydraulic limes as such, whatever may be their composition, which, when quenched and tempered with water, are capable of continuous and uninterrupted induration, whether in air or in water. The constituents which impart these properties to pure limes are silica, alumina, oxide of iron and magnesia. The proposals of Heusinger von Waldegg, based on the percentage of clay present, and of Feichtinger on analogy with Pozzuolana, Roman or Portland cements, etc., to classify these limes, are considered, together with the definitions of Michaëlis and Hauenschild. For the uniform testing of such limes a series of regulations are set down for use in Germany, and these are compared with the rules employed in Switzerland; but the Author calls attention to the imperative need of a standard specification, such as has been adopted in the case of Portland cement. A statement is given of the various facts which have been investigated in the series of experiments here recorded, and the limes have been tested: (1) By slaking and yield of hydrate; (2) weights, both as respects specific gravity and the weight of a given volume filled in various ways with the slaked lime; (3) loss on ignition; (4) fineness of grinding; (5) time of setting; (6) fixity of volume, soundness of pat; (7) yield of mortar and suitability for plastering; (8) tensile and compressive strength; (9) adhesion to tiles; (10) resistance to frost; and (11) chemical composition. These tests have extended over a series of years from 1896 to 1903, and the results obtained in the case of numerous samples, are arranged in Tables. Full explanations are appended of the mode of conducting the various tests. The chemical analyses are in all cases those of lime-samples freed from water and carbonic-acid gas. In conclusion, the Author appends the specification adopted by the French Marine Department for the Teil lime used for the Toulon harbour works.

G. R. R.

Decomposition of Cements by Water Charged with Sulphate of Lime. J. Bied.

(Annales des Ponts et Chaussées, 1902, p. 95.)

The Author remarks that while the attention of engineers has long been directed to the decomposition of cements by the action of sea-water, no attention appears to have been paid to works executed in fresh waters which are charged with alkaline sulphates. The decomposition caused by such water is, however, more pronounced for three reasons:—first, owing to the absence of seaweed and shells, which form a protecting coat in sea-water;

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secondly, the more energetic decomposing action of water charged with sulphate of lime; and thirdly, the deposit of salts in the interior of the structure, brought about by the constant evaporation on the face exposed to the sun's rays.

In the four succeeding sections the Author describes the investigations made in the following structures:—The Alicun Tunnel, the Boufarik fresh-water conduit, the Rimont and Plagnotte tunnels, and works in South Algeria. In all these cases he gives an analysis of the water causing the decomposition, particulars of the cement used, and the extent of the decomposition and damage caused. Two Tables are also given detailing the results of laboratory experiments made by Mr. Bonino.

In conclusion, the Author states that he is carrying out experiments to determine the most suitable cement for resisting decomposition, and urges that wherever practicable experiments should be made and results recorded, in order, if possible, to arrive at a satisfactory solution of the difficulty.

H. I. J.

Vertical Bars of Cement-Mortar Tested by Means of Torsion.

L. DEVAL.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, March, 1903, p. 408.)

These experiments were undertaken by the Author in order to ascertain whether this process lends itself to rapid tests of cements, and also to prove whether the results obtained are proportionately in accord with the formula of Mr. Le Chatelier, $\frac{C}{1-S}$, where C = weight of cement and S the volume of sand contained in 1 litre of fresh mortar. The bars were in all cases 0·78 inch square in section, and from 4·7 inches to 5·9 inches in length. Seine sand (3 to 1) was used, which contains about 40 per cent. of calcareous matter. The briquettes were in consequence of their friablity allowed to remain for 48 hours in the moulds before being placed in water; they were tested at the end of 28 days. The upper end of each bar was let into a lever-arm fixed horizontally, while the other end was inserted into a base plate, which served to keep the bar in an upright position. The torsion thus took place throughout the whole length of the bar, and when test-pieces of 5·9 inches in length were used, it was possible in most cases to obtain three successive tests with the same block. These tests in no case gave uniform results: the first rupture generally involved the least stress, and the two subsequent tests needed more force to effect the rupture. No doubt the first fracture would occur in the weakest part of the bar, and since all parts of the bar are exposed to the same stress, the first fracture would as a rule show inferior results to those which follow. It is herein taken for granted that the part of the bar inserted in the base receives no strain. The

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range of values in the amount of torsion may vary from 3·8 per cent. to 13·7 per cent. for a bar of the same composition, and as a mean of 400 experiments the proportionate variation was found to be 4·6 per cent. for mortars with 1 cement to 3 sand, and 5·6 per cent. for mortars with 1 cement to 5 sand. Graphic diagrams are given of various samples tested, and the results are set forth in Tables, which show similar samples of cement tested by tension and by torsion. This latter plan of testing accords generally with the proportional figures obtained for tension tests; but more experiments are needed to verify the formula of Le Chatelier.

G. R. R.

Loading Tests on a Ferro-Concrete Plate. MELAN.

Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1903, p. 879.)

The ferro-concrete plate tested (in Brünn) had the following dimensions:—Length between supports, 3 metres (9·8 feet); width, 120 centimetres (47½ inches); thickness, 12 centimetres (4¾ inches), and was strengthened by two double-tee girders (Profile No. 8), together with fourteen iron rods each 2 metres (6½ feet) long, and 5 millimetres (¼ inch) in diameter, six being inserted longitudinally and eight diagonally in the form of an X. The total weight of the plate was 1,074 kilograms (2281½ lbs.); the strain on the girders was equal to 809 kilograms per square centimetre (11,506 lbs. per square inch), and the resulting flexure amounted to 12 millimetres (½ inch). The concrete consisted of 1 part by volume of Portland cement and 6 parts of sand and gravel, and 15 weeks were allowed for setting before applying the test. The load was composed of concrete blocks, set on edge, with small interstitial spaces between, to ensure uniform distribution. The initial load amounted to 4,181 kilograms (9,198 lbs.) which increased the flexure at the centre of the plate to $\frac{17}{25}$ of an inch rising to $\frac{18}{25}$ in 24 hours, and diminishing to $\frac{14}{25}$ on the removal of the load. The second loading attained a weight of 8,264 kilograms (18,180 lbs.) and raised the degree of flexure to 27 millimetres (1⅛ inches) which increased to 28·5 millimetres (1⅛ inch) by the end of 4 days. The load was increased to 12,700 kilograms (27,940 lbs.) before any cracks could be detected, these then showing at about 90 centimetres (3 feet) on either side of the centre, *i.e.*, at the termination of the embedded rods. The flexion was 40 millimetres (1⅛ inch) but increased another ¼ inch in the next 24 hours. Finally the load was increased to 14,000 kilograms (30,800 lbs.) without breaking the plate, though left for 14 days, the flexure increasing to 61 millimetres (2¼ inches). No damage was produced on the pressure side of the plate.

C. S.

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The Initial Tensions in Ferro-Concrete Girders.

K. Haberkalt.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1903, p. 66.)

In the case of a freely suspended concrete girder, reinforced on the one side only, and not exposed to the influence of any load, the curvature produced by contraction in setting is expressed by the formula—

$$\delta = \frac{L^2(1-\mu)^2}{4\rho},$$

wherein L represents the length of the girder, μ the specific contraction per unit of length, ρ the radius of the curved neutral stratum.

The methods by which this formula are attained are set out at length, with extensive calculations for determining the resistance of given profiles in respect of load, and for determining the dimensions of a girder to bear a given load. The Paper is also illustrated with diagrams and curves.

C. S.

Cracking of Stonework by Cementing Iron Rods with Sulphur.

Luigi De Gaetani.

(Giornale del Genio civile, Rome, September, 1902, p. 425.)

The two groups of statuary, surmounting at a height of 34 to 39 metres (112 to 128 feet) the entrances to the Bank of Italy in Rome, were found by the Author, who is Engineer to the Bank, to have developed in the course of a few years a number of cracks, some so minute as to be scarcely more than capillary, and others gaping as much as 4 to 5 millimetres (0·16 to 0·20 inch). Each group comprises three seated figures, about three times life-size. They were executed in sound close white limestone from quarries near Tivoli; each figure was made up of six or seven pieces, which had been worked, relatively to the natural bed of the rough blocks, in the direction most favourable for stability. Some of the component pieces weighed more than two tons. They were put together with iron rods, inserted through holes bored from 35 to 65 millimetres (1⅜ inch to 2½ inches) diameter, and secured by cotters; both rods and cotters had been well tinned, and the clearances round them were run in with sulphur. On the detection of the subsequent cracks, the surface of the rods was found to retain no trace of tin, but to be covered with a thin coating of black dust, which proved to be ferrous sulphide; in some places, where the corrosion had continued longer and gone deeper, the iron was scaled with rust. For remedying so dangerous a condition of the sculpture, caused by expansion attending combination of the sulphur with the iron, the sulphur cement surrounding the

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iron rods was drilled out by means of tubular crown rock-drills, of rather larger internal diameter than the rods; the crown was cut with saw teeth, which were hardened with prussiate of potash. The pulverized sulphur was washed out of the holes by jets of water; the iron rods were drawn out, repolished, and put in again with fine liquid cement run in round them, instead of sulphur. The cement adheres perfectly to the iron, and preserves it from oxidation; these advantages, coupled with the ease with which it can be employed, should render it preferable to any other material for setting long rods.

A. B.

Heat-Transmission Through Metal Plate. L. Austin.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 1890.)

When heat is transmitted to a liquid by conduction through a certain thickness of metal, the fall of temperature from the outside of the plate to the liquid is not continuous, there is a sudden step downwards on the inner face. Experiments were carried out by the Author with the object of obtaining a direct measurement of this discontinuity. His apparatus consisted of a closed wrought-iron box, 10 inches by 10 inches by 20 inches long, divided into two compartments or cells by a wrought-iron plate 3 centimetres ($1\frac{3}{16}$ inch) in thickness. One cell contained water, the other oil, and small paddle-wheels were provided for stirring up the liquids. Ordinary mercury thermometers were inserted through the iron covers at about the centre of each. The fall of temperature through the central wall and the difference of temperatures of the water-face of this wall, and the water closely adjoining were measured by thermo-electric circuits, the junctions being placed in holes bored in the dividing plate so as to avoid the great variation of temperature of the metal in contact with the mass of liquid. The oil was heated by gas-burners applied to the bottom plate of the box. The quantity of heat passing from the oil to the water is proportional to the temperature gradient through the central partition, measured in degrees per centimetre, and to the conductivity of wrought-iron. This latter value was found by separate experiments to be 5,040 calories per square metre per hour at 100° C., the gradient of temperature being unity with degrees Centigrade and centimetres as units. (33·8 British thermal units per square foot per hour.[1]) At 18° C. this became 5,330. As regards transfer of heat from the metal plate to the water; with the water boiling but not stirred by the paddle, the resistance to transmission of heat from the iron surface to the water in contact with it was equivalent in effect to from 1·2 to 2 centimetres (0·471 to 0·787 inch) thickness of iron. Vigorous stirring by means of the small paddle reduced the resistance to about 0·75 centimetre (0·295 inch). With the water at a temperature lower than boiling point

[1] The temperature gradient being unity for degrees Fahrenheit and feet.

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and not stirred, the resistance rose to 10 centimetres (3·93 inches) of iron; stirring brought this down to 1 centimetre (0·39 inch). These figures give also a measure of the discontinuity in the fall of temperature from the metal to the water.

If the resistance in question is assumed to arise from a thin layer of water on the iron surface, its thickness must be about 0·1 millimetre (0·004 inch), as the conductivity of iron is about 100 times that of water. The action of stirring seems to be in aiding the circulation of the water, and it consequently equalises the temperature. It apparently also diminishes the thickness of the layer of water adhering to the surface of the iron.

J. G.

Effect of Long-continued Stress on Heated Metal. R. STRIBECK.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 559.)

The experiments were carried out on bars of copper and certain alloys by subjecting them to tensile tests for various periods up to 31 hours, the temperature of the bar being raised by enclosing it within an electric oven. The inner surface of the oven—next the bar—consisted of a nickel tube, and on the outside of this was a spiral of platinum wire into which an electric current was fed, and varied in strength as desired by means of resistances inserted in the circuit. The whole was enclosed within a thick mantle of non-conducting material. Careful preliminary experiments were made in heating the bar, with a view to render the determination of the mean temperature as exact as possible. Six thermo-electric circuits were used, some of them sunk into holes drilled in the bar.

On the basis of the information gained in these tests, the Author has designed a new electric oven which he proposes to utilise for further experiments. He thinks the method of enclosing the bar in a bath of hot liquid inferior to the electric oven. It was found that, before putting the bars in the testing machine, it was advisable to subject them to a considerable heat for some time in a separate oven; this eliminated the effects of the previous treatment of the bar as regards working in the cold state, &c., and generally lowered the yield point, but did not affect the ultimate strength. The copper bars tested were 180 millimetres (7 inches) in length over all, 116 millimetres (4½ inches) between shoulders and 10 millimetres (0·4 inch) in diameter. As regards ultimate strength, tests of ordinary duration gave results exceeding those of long duration by 12·2 per cent. at 200° C., 60·8 per cent. at 300° C., and 168 per cent. at 400° C. The actual strengths were as follows: At 200° C., 11·05 and 9·83 tons per square inch; at 300° C., 9·9 and 6·10 tons per square inch; at 400° C., 7·74 and 3·00 tons per square inch.; the higher figures relating to tests of ordinary duration. At 0° C the strength is not affected by the duration of the stress, being about 2,400 kilograms per square centimetre (15·2 tons per square inch). Some bars were also

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broken at low temperatures and at − 200° C. the strength was 3,700 kilograms per square centimetre (23½ tons per square inch). The extension was also greater with tests of the ordinary duration, the difference being, however, comparatively slight up to nearly 200° C. when it suddenly increased, and at 300° C., while the extension in ordinary tests was about 47 per cent., those in which the stress was applied continuously for some hours only gave an extension of 23 per cent. The contraction of area varied in a similar manner to the extension. The final result is that whereas, in experiments of ordinary duration, the strength, extension and contraction of copper bars only begins to diminish rapidly beyond 300° C., in tests lasting on an average about 10 hours, the strength decreases quickly after 200° is passed.

J. G.

The Dilatation of Steel at High Temperatures.

G. CHARPY and L. GRENET.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 30 April, 1903, p. 464.)

Allusion is made to the importance and value of the study of the effects of elevated temperature upon steel, in view of the precious indications afforded by these researches as to the complex changes which take place in the alloys of iron and carbon, when exposed to great heat, and which, in the hands of Gore and Barrett, furnished the first precise details concerning the phenomena of recalescence. Gore's discovery in 1869 that, during the cooling process of steel wire when at a dull red heat, there was a momentary dilatation, and the subsequent researches of Barrett in 1873, which resulted in the determination of abnormal elongations of such wire, both during the heating and cooling processes, accompanied by an elevation of temperature during the cooling, gave rise to the theory of so-called recalescence. An account follows of the experiments of Evrard in 1887, together with figures of the machines employed by him and graphic diagrams indicating by an interrupted curve the changes in expansion. Svedelius published in 1897 an important essay on the transformations of iron and steel as recorded by the dilatometric method, and the apparatus he employed is described and illustrated, as is also that made use of in 1898 by Le Chatelier and Chantepie. The Authors adopted a modified form of the last-named apparatus, of which detailed illustrations are given. The precautions taken by them to guard against errors of observation are explained and the results are set forth as graphic diagrams. These diagrams clearly indicate the sudden changes that occur at a temperature of about 800° C. Analyses are given of the different kinds of steel which were examined, with amounts of carbon ranging from 0·03 per cent. to 3·50 per cent. Below a temperature of 700° all samples of steel, what-

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ever may have been the percentage of carbon present, possess very similar coefficients of dilatation. When the temperature rises above 700° the phenomena of the transformation of the steel become apparent, no matter what may be the proportion of carbon contained in them. At the temperature of transformation, steels with less than 0·85 per cent. of carbon become contracted; those containing more than 0·85 per cent. of carbon expand. After the rapid contraction, which takes place at 700°, a much more extended zone of transformation is observable with a lower coefficient of expansion than before. The Authors discuss the so-called pyrometric and dilatometric methods and compare the results obtained by both systems. The researches of Roberts-Austen, which are in general accord with the results obtained, are examined, and it is stated that the theory of Bakhuis-Roozeboom, with respect to the phases observable in iron and steel, serves perfectly to interpret the phenomena herein recorded. Certain observations on the behaviour of nickel-steel follow, which are fully illustrated with graphic diagrams, together with records of the results at which the Authors have arrived.

G. R. R.

Expansion of Iron and other Metals at High Temperatures.

W. DITTENBERGER.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 1532.)

The expansion was measured on round bars about 0·5 metre (1·64 foot) in length and 7 millimetres (0·27 inch) in diameter. Marks were cut near the ends of the bars, and the alteration of length observed by means of a microscope at each end fitted with ocular micrometer. The heating was effected by placing the bars in porcelain tubes enveloped in coils of nickel wire through which currents of electricity were passed. The microscopes were read first with no current passing, next the current was applied till the temperature reached 250° C., and from this point observations were taken continuously up to as near to 1,000° C. as the bar remained straight enough for observations to be worth taking.

Bars of wrought iron, mild and hard steels and cast iron were tested. Above 500° C. the expansion was very irregular, and it was evident that the metal was undergoing changes in its condition altogether apart from expansion due to rise of temperature.

The observations are put on record in the Paper, and while the expansion cannot be expressed exactly by any simple formula, an approximation may be obtained by evaluation of the expression $10^9 \lambda = a t + b t^2$. λ is the expansion per unit length, t is the temperature in degrees Centigrade, and a and b are constants for which values are stated for the different kinds of iron investigated. For wrought iron and mild and hard steels, a varies from 11,181

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to 11,705, and b from 4·64 to 5·42, while for cast iron a varies from 9,794 to 9,836, and b from 6·04 to 6·18. This formula gives approximately correct values from 0° C. to 500° C. With the exception of cast iron, the irons showed very little permanent change of length after cooling. In the case of one cast-iron bar the permanent alteration of length was 0·73 millimetre (0·0287 inch).

Copper, aluminium, brass and bronze were also subjected to investigation, and the results analysed in the same manner as those for iron. For konstantan, an alloy of copper and nickel, the expansion was proved to be derivable from the figures appertaining to its constituents. The phenomenon of "flow" was strongly evident in one of the brasses, beginning at a temperature approximately that of the melting point of zinc (419° C.). The alteration of length was at the rate of 0·1 millimetre per hour, and it did not entirely disappear after the bar was cooled to ordinary room temperature.

Note.—In a Paper following after the above, Professor C. Bach, of Stuttgart, gives the results of investigations into the elasticity and strength of the irons for which the expansion had been measured. The information is in tabular form, and also includes statements of the chemical analyses of the metals.

J. G.

Corrosion of Metals in Sea-Water. DIEGEL.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, March 1903, p. 93.)

In continuation of a former paper respecting the life of the more useful copper alloys in sea-water,[1] the Author now deals in the same way with the malleable nickle-copper alloys, in order to determine the influence of nickle upon the behaviour of alloys of copper in sea-water, the protective action of iron upon other metals, the causes of the rapid deterioration of copper pipes at sea, etc. Table I. gives analyses and general properties of the nickel-copper alloys experimented upon. The Author describes them, and gives the percentage composition suitable for various commercial purposes.

Table II. compares the strength with that of iron and steel, and shows the nickel alloys to be very nearly equal in strength to steel, whilst they withstand the oxidizing action of the air and the destructive influence of sea-water. An addition of 5 per cent. aluminium about doubles the strength, but makes the casting more difficult, and reduces to narrow limits the temperatures between which the alloy is malleable.

The solvent action of sea-water, and the formation of galvanic

[1] Marine-Rundschau. Part ii. 1898; Verhandlungen des Vereins zur Beförderung des Gewerbfleisses. 1889, p. 313.

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couples are aided in the work of destruction by the presence of air, by differences of temperature, and the proximity of electric currents.

The tests were carried out on bars prepared like ordinary tension test-bars, having 72 square millimetres (0·112 square inch) cross-section and a length of 100 millimetres (3·9 inches). These bars were rivetted to plates of different metals and alloys, in contact with which it was desired to test them, and they were suspended by a wire of the same material as the plates, from a wooden bridge in Kiel Harbour. Three bars were tested for strength after 18½ months, and other three after 32 months; full particulars as to loss of weight, strength, etc., being given in Table III. and photographic reproductions of the specimens in the accompanying plates. Nickel-copper and its alloys suffer less in sea-water, when in contact with other metals than when alone. The protection by contact with copper- and tin-bronze is not considerable, but iron completely prevents corrosion. The Author next proceeds to examine the influence of nickel upon copper-zinc alloys in sea-water. The results of a 12-months' test are given in Tables V. and VI. These may be summarised as follows:—

Copper alloys containing 24 per cent. zinc, in contact with copper or alloys rich in copper, are attacked almost like other copper alloys; when they contain 28 per cent. zinc and more, the corrosion is considerably greater, due to the extraction of the zinc. An addition of 15 per cent. nickel considerably increases the life of such alloys when in contact with copper, etc., and exposed to sea-water, but unfortunately copper-zinc-nickel alloys are not malleable.

The position in the potential series affords no exact measure of the resistance to corrosion. Tables VIII. and IX. show the results of experiments with iron and copper alloys in sea-water, indicating the protective effect of iron whether in direct contact or in connection with the metal which it protects.

E. H. S.

Corrosion of Metals in Sea-Water. DIEGEL.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, April, 1903, pp. 119–152.)

The Author refutes the common opinion that impure metals in sea-water corrode faster than those which are pure. An addition of phosphorus to zinc-bronze has been shown to improve its capacity for resisting the action of sea-water (Marinerundschau, 1898, Pt. II.), and its effect is the same upon iron. Experiments follow to show that pure copper exposed to the action of sea-water for 28 months showed a loss of weight nearly thirteen times greater than that of copper containing 6 per cent. arsenic. Two wooden steamships, similar in construction, and exposed to similar con-

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ditions, had their hulls copper-sheathed. The copper of the older ship had not particularly suffered after 10 years' service, whereas the metal of the newer ship was so perforated with pit-holes after six months that its renewal became necessary. The analyses of the metals were as follows:—

	Cu.	Pl.	Fe.	Sb.	As.	Ni.	Residue.
First case .	99·35	0·20	Trace	0·02	0·24	0·20	— per cent.
Second case.	99·885	Trace	—	—	0·0022	Trace	CO_2 „

Further experiments and a consideration of all circumstances appear to indicate that the difference was due to the impurities present in the first case.

The experiments further show that there is no material difference in the action of sea-water upon copper whether it is prepared by smelting or electrolytically; that annealed copper is twice as strongly attacked as copper cold rolled, the strength at the elastic limit being also five times higher in the latter case; galvanizing copper protects it only for a short time, and after the destruction of the zinc the corrosion of the copper proceeds so much the faster; metallic contact with iron protects copper, but not completely.

The Author next deals with the action of sea-water on copper and brass tubes, reviews the opinions of the best authorities as to the causes of deterioration and the means to be adopted to counteract them as far as possible. The causes are classified under three heads: (1) The natural tendency of certain kinds of copper to corrode in sea-water; (2) the presence of atmospheric air; (3) the action of electric currents. In Table 13 the Author has collected the results of tests on specimens, both good and bad, which have been taken from ships, with analyses of the metal in each case, and other particulars. These appear to confirm the preceding experiments in respect that pure copper is in general more readily attacked than impure copper under similar conditions, that a high proportion of arsenic is beneficial; and that the presence of copper protoxide favours the process of destruction perhaps in all kinds of copper.

The Author failed to demonstrate the presence of electric currents due to the friction of the water in the pipes, but he quotes an experiment to show that the rotation of the propeller of a torpedo-boat set up an electric current along a wire connecting it with the torpedo which increased in intensity from 0·065 volt at low speed to 0·142 volt at 1,080 revolutions, decreasing to 0·110 volt at 1,650 revolutions per minute.

That the corrosion of these pipes is not due to fatty acids, as some suppose, seems to be proved by the fact that pipes conveying clean sea-water are even more attacked than those which serve for the discharge of the fatty bilge-water.

The Author points out the desirability for systematic experiment and observation based upon the results so far obtained. He suggests as the most probable sources of trouble: (1) the use of

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purer copper than formerly; (2) the action of a galvanic couple formed by the copper and the products of its corrosion in sea-water; (3) in the case of the condensing-water pipes, the action of an electric current set up by the working of the pumps.

He suggests that upon several ships whose tubes have hitherto been rapidly destroyed, these tubes should be replaced by others made of copper with—(*a*) about 0·5 per cent. arsenic; (*b*) 1 to 2 per cent. silicon; (*c*) 5 per cent. nickel; (*d*) 42 per cent. nickel; and that these should be continuously kept under observation. An addition of phosphorus would possibly be advantageous.

Some suggestions follow for the protection of the pipes against the injurious effects mentioned above under (2) and (3).

E. H. S.

Dry-Rot and other Fungi Attacking Timber.[1] Dr. H. Zikes.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten Vereines, 1903, pp. 145-148.)

After describing the development and life-history of the dry-rot fungus (*Merulius lacrymans*) the Author deals with the means by which this organism may be accidentally introduced into sound timber, and mentions among them neglect of disinfection by workmen proceeding from a job in repairing the ravages of dry-rot to other premises where the timber is sound; the use of old timber from infected premises, and the practice of storing old and probably infected woodwork along with new timber. Contributory influences that favour the spread of dry-rot are the presence of moisture and the absence of ventilation. Where the fungus has gained access, all the visibly affected woodwork should be removed, and also the adjoining apparently sound timber for at least 3 feet round; the adjacent brickwork must be well cleaned, brushed over with creosote oil, and faced with good plaster; and if the underlying soil be affected it also should be removed and the site treated with creosote oil, etc. As a filling-in material, washed gravel is preferable to cinders, the quantity of moisture retained by the former being only $\frac{1}{20}$ that of the latter.

In adopting antiseptic preventives, the timber should be impregnated to a depth of about $\frac{1}{4}$ inch by steeping for 24 hours in either creosote oil, a 2 per cent. solution of sodium dinitrocresol (antinonnin), or antigermin (dinitrocresol and copper hydroxide), a 5 to 10 per cent. solution of antipolypin (sodium B-naphthol, sodium fluoride and caustic soda), a 5 per cent. solution of hydrofluoric acid or hydrofluosilicic acid, or a 1 per cent. solution of corrosive sublimate. Formalin is too volatile to be efficacious against dry-rot.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 419; vol. lxxxvi. pp. 381, 384; vol. cliii. p. 392.

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A rarer fungus in woodwork is *Polyporus Vaporarius*. It inhabits live timber and may continue its destructive action after the trees have been felled and worked up. The mycelium is always white, and the felted network is devoid of the broad water-vessels exhibited by the dry-rot fungus. It will not grow if the timber be dried before use and proper ventilation secured. Other fungi attacking timber are—*Lenzites sepiaria* and *abistina* on coniferae, and *Daedalea quercina* on oak; all of which grow only in very damp wood (mine timbers, bath-houses, etc.), and allow merely the organs of fructification to appear on the surface, the mycelium occupying the interior of the wood.

C. S.

Specific Heat and Explosive Force of Gases.

Dr. Arnold Langen.

(Zeitschrift des Vereines deutscher Ingenieure, 1903, p. 622.)

The investigations, carried out in the Technical High School at Dresden, were directed towards obtaining more information as to the physical properties of exploding gases, with a view specially to the perfecting of the thermo-dynamical theory of internal combustion motors. Mixtures of hydrogen and oxygen, carbon monoxide and oxygen, with varying quantities of inert gases, were exploded in a hollow sphere suspended in water, and diagrams were taken of the varying values of the pressure. The diagrams showed the pressure to rise rapidly during the period of general explosion, at the end of which the rate of increase of pressure had attained the maximum value. Following on this came a period of mixed explosion and cooling, during which the rate of increase of pressure fell and in the end became negative, when a period of general cooling and reduction of pressure set in. The results of the experiments are set out in tabular form, and the Author also gives *resumés* of results attained by earlier investigators. Some of the pressure diagrams exhibited irregularities in the pressure, and the Author associates these irregularities with the dissociation of the gas already formed by the explosion, and its re-explosion. The Author specially investigated these peculiar diagrams by methods which he says cannot be discussed in his Paper. The results are generally comparable to those obtained by Mallard and Le Châtelier. If it is assumed that the increase in the molecular heats of gases is simply proportional to the temperature, the following formulas give results corresponding with the observed pressures of explosion.

Simple gases . . .	$C_v = 4{\cdot}8 + 0{\cdot}0006\,t$
Water vapour . . .	$C_v = 5{\cdot}9 + 0{\cdot}00215\,t$
Carbonic acid . . .	$C_v = 6{\cdot}7 + 0{\cdot}00260\,t$

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For comparison the Author gives the values for the molecular heat of the same gases as obtained by Mallard and Le Châtelier, as follows:—

Simple gases . . .	$C_v = 4{\cdot}8 + 0{\cdot}0006\ t$
Water vapour . . .	$C_v = 5{\cdot}61 + 0{\cdot}00328\ t$
Carbonic acid . . .	$C_v = 6{\cdot}3 + 6 \times 10^{-3}\ t - 1{\cdot}18 \times 10^{-6}\ t^2$

J. G.

The Measurement of a Meridian Arc at Spitzbergen.

A. HANSKY.

(Revue générale des Sciences, 1902, p. 1117 *et seq.*)

The measurement of an arc near the North Pole is a matter of great importance for the accurate determination of the shape of the globe. The idea of making such measurement at Spitzbergen was first suggested by Sabine, but was not carried into effect. Thirty years later, in 1861, Otto Torell proposed to the Swedish Academy of Sciences to ascertain whether the configuration of Spitzbergen was adapted to astronomical observations, and the results of the investigations of two Swedish expeditions showed that there was a series of elevated points, all situated near the coast visible from one to the other, so that a chain of triangles could be formed from the South Cape, 76° 30′ lat. N. to Rossö 80° 50′ lat. N., enabling a meridian arc of about 4° to be measured. In 1897 the Stockholm Academy proposed to the St. Petersburg Academy that this important scientific enterprise should be undertaken jointly. The Russian-Swedish expedition started in 1899. The measurement of the base-line was rendered more easy and more rapid by the use of an appliance invented by Jäderine, and by adoption of nickel-steel wire with a very low coefficent of expansion. Jäderine's original apparatus consisted of wires 24 or 25 metres in length and 1·7 millimetres thick. At the ends of these wires there were two small scales graduated in millimetres. Two dynamometers maintained the wires at a given constant tension. Along the base-line special tripods were placed at intervals of 24 or 25 metres, and with the wires the exact interval between marks on two tripod-heads was measured, the wires being stretched with a force of 10 kilograms at each end. One observer held the zero of his scale on the mark, whilst another at the same moment read the position of the mark on his scale. These readings were repeated four times with two different wires. With the nickel-steel wire the correction for temperature is negligible. The operations are thus greatly simplified. The measurement of a base-line of 6 kilometres in length with compensated bars would have required fifteen days, whilst, with the new method, the work was completed in four days, operations

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being conducted at night between 8 P.M. and 4 A.M. The degree of accuracy obtained was 1 in 400,000. The triangulation was completed towards the close of 1901, and the 14 photographic illustrations given by the Author indicate the difficulties that had to be overcome in the construction of the monuments from which the observations were made.

B. H. B.

The Mechanical Sorting of Postal Parcels. D. BELLET.

(Revue Générale des Chemins de fer, Feb. 1902, p. 97; La Nature, 6 June, 1903, p. 10.)

At the Orleans Railway terminus in Paris from 18,000 to 26,000 parcels are despatched each day to the various stations on the line, some of these parcels being made up in sealed wagons for the principal towns, while those for places of less importance are packed in hampers or baskets. The bulk of the deliveries take place daily between the hours of 6 P.M. and 8 P.M., shortly before the departure of the chief goods trains. The motive power for the whole of the plant here described and illustrated is electrical. All the parcels that reach the station addressed are furnished with a ticket and chalk-mark, placed on them by the agent, which indicates whether they are destined for special trucks to go in bulk, or whether they will have to be sorted into smaller packages. If a parcel is intended for a goods wagon, it is at once dropped into one of nine shoots, which conveys it by means of an inclined plane to one of two endless belts of the well-known type, which are similar in all respects to the one described as in use for passengers' luggage at the Quai d'Orsay.[1] These belts pass on the parcels to a sorting-table in an underground chamber, where the clerks pick out, in accordance with the chalk-mark, each of the packages and remove them to one or the other of six shorter belts, running at right angles to the main conveyors. By reference to a series of sectional and other diagrams an account is given of the rapid classification and transportation, with shunting arrangements for all kinds of parcels in accordance with their destination. Even for the package into baskets special provision is made, by means of endless inclined belts which convey the sorted parcels at the rate of 3,600 per hour to the places where the various baskets or hampers are made up. These are situated at a level of 17 feet 6 inches above the loading platform for the trains. It is stated that this mechanical sortage answers perfectly in practice, and has enabled half the previous staff to deal with double the amount of work in a similar time, while the total daily cost of the electrical driving does not exceed 16*s.* 10*d.* G. R. R.

[1] Minutes of Proceedings Inst. C.E., vol. cxlix., p. 377.

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The Lebaudy Balloon. Lt.-Col. G. Espitallier.

(La Nature, 2 May, 1903, p. 337.)

This navigable balloon, which has a total length of 187 feet, is in its general outline in the form of a spindle, but it is not symmetrical, as the greatest diameter of 32 feet is situated at a distance of 81·7 feet from the prow, or 105·3 feet from the poop end. The front part takes the shape of an elongated cone and the rear end is semi-spherical. The inflated balloon does not completely assume the form due to the revolution of the semi-longitudinal section, but represents the solid figure so described cut by a horizontal plane parallel to the central axis and 11·48 feet below it. The oval boundaries of this plane base are formed of rigid steel tubes, to which the car is suspended by steel wire ropes. Another peculiarity of this framework is a kind of vertical skeleton keel, which traverses it from end to end and which is provided with cross-bracing to the outside of the frame. Details are given of this framework and of the car with its machinery and screw propellers. The material which covers the balloon is composed of two thicknesses of light cotton fabric, with a thin sheet of india-rubber interposed between them. To prevent the influence of sun-light on the fabric, the outer covering of cotton has been dyed yellow, and, in order to protect the internal rubber from the action of the oxygen contained in the atmosphere, each of the cotton linings has received seven or eight coats of a special solution of indiarubber in a mixture of benzene and bi-sulphide of carbon. The total weight of the material thus prepared is under ten ounces per square yard, and it is almost absolutely impermeable to hydrogen gas. The car, which is suspended 17·22 feet below the base, is 15·74 feet long by 5·25 feet wide. The full capacity of the balloon is upwards of 80,000 cubic feet, and in order to maintain the form unalterable there is an inner compensating air-balloon with a capacity of about one-seventh of the above volume, or nearly 11,000 cubic feet. Details are given of the weights of the various parts of the balloon and of the precautions taken to avoid accidents due to ignition of the gas or of the petroleum spirit used in the 40-HP. motor, which drives a pair of two-bladed screws 9·18 feet in diameter at 1,000 revolutions per minute.

G. R. R.

Water-Tube Boilers.

(Scientific American, 87, p. 148, Sept. 6, 1902.)

Tests made on tubes 3 inches in diameter showed that when the tube was simply expanded into the tube-plate it required a force of 6,300 lbs. to withdraw it, while if the tube was expanded and then flared a pull of 19,700 lbs. was required. From this it is

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calculated that, with 4-inch tubes and a boiler pressure of 200 lbs. per square inch, the factor of safety of the attachment of the tubes to the plate is only about 2½ when the tubes are simply expanded, and is 7·8 when the tubes are properly flared.

H. R. C.

Calorific Power of Coal. GOUTAL.

(Comptes Rendus, 135, pp. 477–479, Sept. 22, 1902.)

The use of the Mahler bomb calorimeter has frequently revealed discrepancies between actual calorific powers and those calculated by means of the formulas hitherto proposed. The Author has abandoned the use of the formulas of Dulong, Scheurer-Kestner, Cornut, Ser, and Gmelin as being incorrect or founded upon delicate or complicated determinations. Nevertheless, as a simple calculation for finding calorific power, which possesses considerable interest from an industrial point of view, he has sought to establish a relation between calorific power as calculated and the results furnished by trials of fuels. The study of over six hundred samples of coal from different sources has convinced him that the results of trials are closely expressed by the formula $P = 82\,C + aV$, where P = the calorific power sought; C = the percentage of fixed carbon; V = the percentage of volatile matter; and a = a variable coefficient which is a function of the amount of volatile matter V′ in pure combustible (*i.e.*, without ash or water), so that

$$\left(V' = \frac{V.}{100C + V}\right).$$

The following curve has been traced from the results of numerous trials, in order to fix experimentally the value of a for different fuels; the abscissas showing percentages of volatile matter V′, and the ordinates the corresponding values of a drawn from calorimetric combustions. For the following amount of volatile matter, viz., 5, 10, 15, 20, 25, 30, 35, 38, and 40 per cent., the coefficient a has successively the values in calories, 145, 130, 117, 109, 103, 98, 94, 85, and 80. In the case of anthracite, a is represented by a constant equal to 100 calories, and the formula becomes $P = 82\,C + 100V$. The error from the use of this formula rarely exceeds 1 per cent. of the actual value in the case of ordinary coal, and is seldom above 2 per cent. in the case of some anthracites and lignites which can be studied only by means of a calorimeter. The curve is applicable in the case of distillation of coal, and to all the varieties of coal from anthracite to lignite. The Author gives the calorific power of pure anthracite at 8,250 calories; that of anthracite coal, with V′ = 5 to 10 per cent., at about 8,550; and a maximum of 8,700 calories for the coals, of which V′ = from 10 to 30 per cent.

F. J. R.

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Machine for Testing Lubricating Oils. G. Dettmar.

(Elektrotechn. Zeitschr. 23, pp. 741–745; Discussion, pp. 759–760, August 21, 1902. Report read before the 10 Jahresversammlung des Verbandes Deutscher Elektrotechniker at Düsseldorf.)

The apparatus described is intended to give a reliable test of an oil with a twenty minutes' trial, the conditions encountered in practice being reproduced as nearly as possible. The machine consists of a single test bearing and a journal fitted with flywheels on either side. The journal having been run up to any desired speed, the motive power is uncoupled and a time-velocity curve is taken as the combination comes to rest, which usually takes five to fifteen minutes. The oil-film used is 0·05 millimetre to 0·1 millimetre, the bearing load 3 kilograms per square centimetre, and the journal diameter 30 millimetres, giving, at 2,000 revolutions, a circumferential velocity w of 3·14 metres per second, and a mean value while slowing down of about 1·5. The Author refers to his former papers for the theory on which many of his deductions depend. Calling μ the coefficient of friction at 1 kilogram per square centimetre, he finds that $\mu = r, w^x, x$ having the values 0·55 at 28° C., 0·485 at 40°, and 0·387 at 70°. The usual final bearing temperature being about 40°, μ'' may be taken as $= r \sqrt{w}$. Calling T_1 and T_2 the times taken with two different oils for the machine to come to rest from the same speed, the Author gives the relation $T_1 r_1 = T_2 r_2 =$ constant, from which it is seen that the friction constant r for any oil is inversely proportional to T, the lubricating value of the oil being therefore directly proportional to T. Values for r are given for six different

Tests of Six Oils.

No.	T 1,400 Revolutions to 0, Seconds.	r.	Temperature °C.	Pfennig per Kilogram.	$r \times$ Price (Relative Economy).	T r.[1]	μ (approximate) at 1 Kilogram per Square Centimetre and 2·0 metres per second (from curves).
1	560	0·05	33·0	32	1·6	2·80	0·072
2	385	0·068	40·8	63	4·28	2·62	0·116
3	339	0·081	40·0	65	5·26	2·82	0·141
4	294	0·088	39·2	42	3·70	2·70	0·144
5	289	0·091	45·5	32	2·91	2·63	0·15
6	274	0·095	42·0	48	4·45	2·60	0·151

[1] T r should theoretically be constant. By adopting No. 1 as their works oil, the Author's Company effect a saving of 25 per cent., or £100 a year.

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oils, but the Paper does not clearly describe how the values were worked out. The value of r is absolutely independent of the prices; indeed, the cheapest oil tested gave the best results. The following relations are given incidentally: (1) μ = constant $\times \frac{\text{r.p.m.}}{T}$. (2) r = constant $\times \frac{\sqrt{\text{r.p.m.}}}{T}$. (3) The total friction is inversely proportional to the thickness of the oil film, and is independent of the load, with bearings forming a closed sleeve, because the oil film maintains a constant average thickness all round. (4) If the bearing is divided into halves, with a space between them, and the top one carries only its own weight, the friction increases somewhat with the load, because the oil film below becomes thinner, while that above remains constant. (5) The Author confirms B. Tower's temperature experiments, and finds that μ is nearly proportional to the temperature Centigrade. (6) The critical velocity at which μ becomes a minimum varies from 0·1 to 0·2 metre per second. (7) With good lubrication the metals used have no influence on the friction. Bearing metal should wear well, and be a good conductor of heat. To avoid waste of time, a hot-water coil is advantageously employed to heat the bearing up to about 40° C., the usual final running temperature. The importance of only testing with one bearing is emphasised. Before testing in the machine, oil should be tried—(1) for acidity, by seeing that it will not tarnish bright copper strip; (2) for liability to harden, by rubbing two oiled plates together, and observing that they do not tend to stick after some hours' exposure in the open. Numerous trials have demonstrated that all trace of oil can be removed from the bearing by washing out with benzine and then using an air blast.

Discussion.—Arnold did not think that, with all oils, μ would vary directly as the temperature. May pointed out that the oil which tested the best when new would not necessarily give the best average results over a long period of use. Wilkens considered that the correct method of investigating friction necessitated the division of the friction into (1) cohesion, (2) internal friction; but Haas regarded the estimation of the total friction as being of the most practical value, and mentioned that his firm tested oils by measuring the final temperature which the oil gives in a standard bearing, this being the simplest method that can be devised. Dettmar, in reply, said that his results always confirmed the relation between μ and the temperature, whatever the oil used. Experiments on the durability of oils are already in progress.

R. C. R.

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Aluminium as a Reducing and a Heat-producing Agent.

H. O. Hofman.

(Technology Quarterly, 15, pp. 93–104, June, 1902.)

The introduction is purely rudimentary, and summarizes the characteristics of the principal reducing agents, giving comparisons with aluminium, in a tabular form, referring in particular to thermo-chemical figures. The Roessler-Edelmann process for the desilverisation of argentiferous lead by means of zinc and aluminium (a modification of Parkes' process), is briefly touched upon. A favourable effect of aluminium is seen in its use in galvanising. By adding 0·001 per cent. of aluminium to the zinc, a much more fluid bath results, a given weight of zinc coating 20 per cent. more surface. The sheets are brighter and keep their colour better. The effects small amounts of aluminium have on the different forms of iron are of great importance. It was discovered by Wittenstrom in the eighties that if 0·5 per cent. to 0·1 per cent. of aluminium were added to a charge of wrought iron heated to pastiness, the iron liquefied so that it could be poured. In making steel castings, an addition of 0·03 to 0·5 per cent. of aluminium has a very beneficial effect in reducing the small amount of iron oxides that are formed, especially in pouring, besides preventing the formation of blow-holes. The commercial use of aluminium as a reducing agent, is further exemplified in the plant of A. J. Rossi, of Buffalo, New York, for the reduction of titaniferous iron ores, who uses an electrical furnace of the well-known Siemens type. The alloys made show a range of from 10 to 75 per cent. titanium, 0·1 to 0·8 per cent. carbon, and 0·015 per cent. sulphur, while the slag assays 80 to 85 per cent. Al_2O_3, and contains 90 per cent. of the aluminium charged. Hall's aluminium process, and the later process of Dr. Hans Goldschmidt are also discussed, a table being given, with reference to the latter, showing the heat-balance in reducing ferric oxide. Although the main object in the Goldschmidt process has been the reduction of refractory metallic oxides, the process is being applied also, as a heat-producer for welding, soldering, annealing, etc.

O. J. S.

Electrically operated Bascule Bridge.

(Western Electrician, 31, pp. 187–188, Sept. 20, 1902.)

A new type of bascule bridge has lately been erected over the south branch of the Chicago River at Ashland Avenue at a total cost of 133,000 dollars, including 41,000 dollars for superstructure and masonry. The centre span is 160 feet long with a clear

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waterway of 140 feet. The two side spans are each 48 feet long. The total width of the bridge is 60 feet, and it carries two street car trucks. Each side of the bridge is operated by two 38-HP. direct-current 500-volt motors, which raise the outer end of the forward section of each half, and at the same time lower the forward end of the back section, whose weight is arranged to nearly counterbalance the forward section. By means of bevel and spur gearing the motors drive double square-threaded steel screws, 7½ inches in diameter, and 30 feet long, upon which travel sliding blocks or nuts, to which are attached the back ends of the operating struts, whose forward ends are attached to the forward section of the bridge. These struts are 12 inches square, built up of channel irons. When tested without the brick flooring on the back section, and therefore somewhat out of balance, 84 HP. were required on starting to open the bridge, falling to 9 HP. when the forward section gets into motion. To lower the bridge, 57 HP. were required to start it downwards. Operating towers are provided on each half, and contain special controllers and pneumatic bridge-locking arrangements arranged to secure the right sequence of events.

E. H. C.-H.

Double-Current Generators and Rotary Converters.

S. WOODFIELD.

(Electrical Review, 51, pp. 569–571, Oct. 3, 1902.)

The objections usually raised against this class of machine, that it is difficult to start and to synchronise, and that it is liable to hunt, are purely imaginary. The latter difficulty is non-existent if the system is well designed, and the engines properly balanced, and fitted with dashpots to reduce the sensitiveness of the governors to small rapid fluctuations; and the method of starting up rotaries by means of a small auxiliary induction motor, running at a higher speed than the rotary, and then bringing the latter down to synchronous speed by loading one phase through a rheostat, makes synchronising an easy matter. Six distinct uses of the rotary converter are enumerated; in this Paper the Author deals chiefly with its employment as a double-current generator, giving both alternating and continuous power at the same time when mechanically driven. For railroad work, a double-current generator has the advantage over two separate machines that the load is automatically shifted from one side of the machine to the other without the efficiency being altered to any great extent. The question of cost is not so serious in this country as in America and on the Continent, where low-speed engines are in vogue. Spares also are reduced to a minimum, thus reducing capital cost. In a rotary used as a converter there is no distortion of field due

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to armature reaction; used as a double-current generator, however, the armature reaction is due to the sum of both currents, and the demagnetising action due to this cause may be so strong as to cause the machine to lose its excitation. For this reason it is often advisable to separately excite a double-current generator. Low frequency and high engine speed are both points which fit in well with the use of these machines, as under these conditions they may be designed with few poles, which means that the diameter can be kept within reasonable limits. After giving formulas for the relations between the current, voltage, etc., on the alternating and continuous side, the Author refers to the use of step-up transformers, which are necessary for the transmission of the alternating current, and of which the cost has to be added to that of the generators. As regards sub-stations, induction motors coupled to direct-current generators are convenient, since no regulation is required on the alternating side. Further, the induction motor gives ample margin for temporary overload, and no transformers, starting motor, or synchronising gear being required, the wages of sub-station attendants can be cut down to a minimum. This, with the absence of hunting, is a good set-off against the better power factor and efficiency obtained with a synchronous set. In a rotary converter sub-station the primary voltage on the transformer must be kept constant, and an induction regulator becomes necessary, which is preferably installed in the sub-station, on the high-tension side.

B. P. S.

Compensated Continuous-Current Generators. F. EICHBERG.

(Elektrotechn. Zeitschr., 23, pp. 817–824, Sept. 11; Discussion, pp. 757–758, Aug. 21, 1902. Paper read before the 10 Jahresversammlung des Verbandes Deutscher Elektrotechniker in Düsseldorf, 1902.)

The arrangement described is one recently patented by Déri, and it closely resembles the designs proposed by Ryan and Fischer-Hinnen. The armature of the machine is of ordinary construction, but the field magnet takes the form of a hollow laminated cylinder resembling in every respect the stator of an induction motor. Two windings are distributed over the slots of the stator, their relative positions corresponding to those of the stator windings of a two-phase induction motor. One of these is the ordinary shunt field winding, connected across the brushes of the machine; the other is a series winding, which forms the balancing or compensating coils. The Author states that an essential feature of the arrangement is the use of balancing coils which are stronger than the armature winding. This allows of any required final adjustment being effected by the use of a shunt across the balancing winding. Diagrams are given of different ways of arranging the

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two windings, and illustrations of the machine actually constructed, with tables and curves showing their performance. On account of the large polar arc (there being no interpolar gaps), a low induction in the air-gap is possible, and the corresponding low saturation of the core allows of an increase of field-strength of from 50 per cent. to 60 per cent., which is unattainable in machines of ordinary construction. The air-gap may be reduced to a mere mechanical clearance. The machines are said to be lighter and more efficient than those of ordinary construction.

Discussion.—Arnold expressed the opinion that probably a larger amount of copper would be required in the field coils than in those of ordinary machines. Déri's machines would, however, be useful in special cases, as the length of the armature could be increased considerably beyond the usual limits. Ziehl stated that there was an actual saving in the field copper; the shunt coil being required to supply only from 30 per cent. to 35 per cent. of the normal armature ampere-turns, the total field copper came to, roughly 1·3 times the armature copper, as against 2 or 3 times the armature copper in ordinary machines. In his reply, Eichberg referred to actual data showing a saving in copper, and a reduction in the total weight of from 10 per cent. to 15 per cent.

A. H.

Starting Single-Phase Motors. A. Schwartz.

(Elektrotechn. Zeitschr. 23, pp. 795–798, Sept. 4, 1902.)

In a single-phase induction motor the reaction between the field and the currents in the end-rings of a short-circuit rotor, when starting, tend to push the rotor out of the field if it be only slightly displaced axially in either direction. When synchronism is nearly reached, however, the altered distribution of currents in the rotor cause this effect to cease and the rotor is drawn back to a symmetrical position by the magnetic attraction on the iron core. This action is utilized for three different purposes in the motor described. First, the rotor is displaced into such a position that its self-induction is sufficiently reduced to give the best conditions for starting. Secondly, the axial motion of the rotor is made to release a centrifugal coupling, thus putting on a load only when the motor has practically reached synchronism. Thirdly, by means of contact rings on the shaft the axial motion is made to switch out the auxiliary starting winding after the motor has started.

A. E. L.

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Marseilles Electric Tramways. H. Dubbs.

(Génie Civil, 41, 1, pp. 229–236, August 9, 1902.)

The Marseilles tramways have a total length of about 125 kilometres, with a great concentration of traffic along some of the central streets. The power is supplied from a generating-station on the banks of the River Huveaune, at a distance of about 5 kilometres from the centre of the town. The boiler-house contains 20 semi-tubular boilers arranged in four groups, with a Green economizer to each group. Water is supplied by means of four duplex pumps driven by an electric motor. A Desrumeaux water-softener is employed. There are two chimneys 60 metres high, and with openings at the top 3·2 metres in diameter. The boilers are arranged on the ring system, and so that each engine can receive its supply of steam either from the boiler from the right or left, so that repairs to the steam piping can be carried out without stopping any of the engines. The engine-room contains five 1,000-kilowatt generating units, three exciting units and the switchboard. Each generating unit consists of (1) a Corliss horizontal, compound, condensing engine, running at 75 revolutions per minute and developing normally 16,070 I.HP. The diameters of the cylinders are 0·9 metre and 1·5 metre respectively, and the length of stroke is 1·4 metre. The governor is capable of adjustment by means of a movable counterpoise actuated by a screw. This adjustment can be effected whilst running either by hand or by means of a motor operated from a switchboard. The shaft carries a 36-ton flywheel in addition to the inductor of the alternator, which weighs 32 tons. The coefficient of variation during the stroke is 1/380 when developing its normal power. (2) A direct-connected inductor three-phase, 5,500-volt, 40-pole 1,250-kilowatt alternator producing current at 25 ∼. They are capable of carrying an overload of 25 per cent. for two hours, or 50 per cent. for two hours. Each exciting unit consists of (1) a compound condensing engine of 120 I.HP., running at 210 revolutions per minute; (2) a direct-connected, 4-pole dynamo of the external armature type. There are six sub-stations, each arranged to accommodate four units consisting of a three-phase step-down transformer made up of three distinct single-phase transformers and a six-phase rotary converter, consisting of a dynamo with external poles. Six-phase converters were used in preference to three-phase, in consequence of their greater output, viz., 1·451:1. The 400-kilowatt converters have 8 poles and run at 375 revolutions per minute, whilst those at 25 kilowatts have 6 poles and run at 500 revolutions per minute. The units as yet installed in the sub-stations are two each in four of them and three in each of the two remaining ones. The current is supplied from the sub-stations to the lines, which are all on the overhead trolley system, at the usual pressure of 550 volts. The high-pressure

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cables are armoured, and are laid directly in trenches 0·8 metre in depth. They rest on sand, and are protected from accidental damage by a covering layer of bricks. The energy loss between the central station and the sub-station does not exceed 3 per cent. at normal load and 5 per cent. at a 50 per cent. overload. The coal consumption per kilowatt delivered at the switchboard was guaranteed not to exceed 1·2 kilogram at the normal output. The actual result obtained is somewhat better than this, viz., 1·043 kilogram. The combined full-load efficiency of alternators, high-pressure feeders, transformers and converters is 0·865, and the efficiency under running conditions is found to vary from 78 per cent. to 82 per cent. The total daily output is from 30,000 kilowatt-hours to 40,000 kilowatt-hours.

The Paper contains a number of illustrations, plans and detailed drawings.

G. W. DE T.

Power Plant in Antwerp steelworks.

(Electrical World and Engineer, 40, pp. 621–622, Oct. 18, 1902.)

A large establishment near Antwerp, comprising blast-furnaces, steelworks, rolling-mills, and tube works, is equipped with a Westinghouse power plant which will eventually have a capacity of 30,000 HP. There are at present two steam-driven sets consisting of 900-kilowatt three-phase alternators, giving 50 cycles and 2,200 volts, and driven at 187 revolutions per minute by triple-expansion marine type engines. Future extensions will be made with gas plant. The plant is run on two independent sets of bus-bars so as to keep the rolling-mill separate from the other circuits. There are four transformer stations in various parts of the works. Induction motors of 325 and 450 HP. for the rolling mills are supplied directly at the high tension, and are provided with controllers similar to those used for electric traction for reducing the speed by about 25 per cent. by means of resistances in the rotor circuits.

A. E. L.

A 10,000-*volt High-speed Locomotive.* W. REICHEL.

(Elektrotechn. Zeitschr., 23, pp. 685–691, August 7, 1902.)

The locomotive built by Siemens and Halske for the experiments on the military railway near Berlin, has reached a speed of 160 kilometres an hour. The highest voltage yet applied is 15,000 at no load, and 13,800 at full load. For speeds of 150 kilometres an hour, the track did not appear to be sufficiently firm, the rails weighing 33 kilograms per metre; consequently higher speeds

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than this have not been properly tested. This defect is to be rectified. The electrical equipment of the original locomotive was in every way successful; but the weight appeared excessive. The present article describes a new one which has been built; it has no transformers, the pressure, 10,000 volts, being applied directly to the motors. The total weight of the train is thereby reduced from 96 to 76 tons, and the four motors give a maximum output of 400 HP. each at 885 revolutions per minute. The locomotive is constructed with two bogies, on each of which two of the motors are mounted, the axles being connected to the motors by toothed gearing in the ratio of 1 to 2. The brakes are worked by pneumatic pressure on the Westinghouse system. The total length is 12·5 metres, and the breadth 2·8 metres. The driver's room is in the middle of the length, and the ends of the locomotive are covered with sheet-iron covers, which can be lifted for the purposes of inspection. The whole with electrical equipment weighs 40,000 kilograms, the motors weighing about 16,000 kilograms. Each motor drives a separate axle, being connected to the axle by toothed gearing at each end, *i.e.*, each motor is placed on its spindle between two-toothed wheels which gear with corresponding wheels on the axle. This arrangement secures symmetry, and also allows a high speed for the toothed gearing, which is fixed at 18 metres per second. The large wheel has 147 teeth, the small one 69; the pitch is 6π millimetres, and the breadth of the tooth 100 millimetres. Tests were previously made with speeds of toothed-gearing up to 25 metres per second; and from these it appeared to be insufficient to run the gearing in a bath of oil or grease. An arrangement is therefore adopted by which the oil is injected on the wheels under a pressure of about 5 centimetres of mercury from a small tank, which is filled under pressure by a pump. The oil must be injected on the teeth on that side on which they engage, and consequently arrangements are made for feeding in the oil from opposite sides on the forward and backward journeys. The motor bearings are 300 millimetres long, and the spindle has a diameter of 190 metres. The air-gap is said to be between 1·5 and 2 millimetres. The rotor has a diameter of 68 centimetres, and a breadth of 30 centimetres. The stator, which receives the high pressure, has 72 slots, and 67 conductors per slot, which are wound in mica tubes. The winding of the rotor consists of flat copper bars contained in half-closed slots; the voltage developed in the rotor at starting is 700. The high-tension cables are brought to the motor through rubber bushes, which are themselves mounted in vulcanite bushes. The starting is effected by means of metallic resistances, and the switchboard arrangements are in general very similar to those on the high-speed car already described. The pneumatic pressure for the brake is supplied by a small pump, driven by a 110-volt motor, which receives its current through a small transformer. After being handed over, the locomotive was tested with gradually increasing voltages, starting with 6,000 volts at 25 cycles, and with speeds between 55 kilometres an hour. On the last test

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11,000 volts were applied at 48 cycles, and a carriage weighing 31 tons was taken as a load, a speed of 105 kilometres per hour being reached. The Author states that an electric train, worked on this principle, and taking 100 passengers, weighs 1,180 kilograms per passenger, whereas a train worked by steam, would weigh 1,800 kilograms per passenger.

W. H. S.

Electric Traction in Relation to Existing Railways.

J. W. Jacomb-Hood, M. Inst. C.E.

(Electrician, 49, pp. 1037–1038, Oct 17, 1902. Extract from Paper read before L. & S. W. Railway Debating Society.)

The Author discusses the limitations of steam working on branch lines due to heavy trains and infrequent service; heavy station expenses; cost of signalling; and wear and tear due to reciprocating engines, and compares these with the advantages offered by electricity. He then outlined a system of electric traction for 70 miles of the L. & S. W. Railway lines, giving the probable number of trains and passengers, the position and capacity of the generating stations. Basing his calculations on 40 trains, and 5,000,000 train miles per annum, and 75,000,000 passenger miles, against the present 1,500,000 train miles and 45,900,000 passenger miles, he shows the financial results that might accrue to the Company. This works out that each additional passenger must contribute only 0·43d. per mile in order to secure to the Company a return on the capital, and above that, $\frac{1}{12}$d. per mile per passenger is all that is necessary to pay 1 per cent. profit.

F. B.

Strength of Concrete. Considère.

(Comptes Rendus, 135, pp. 337–341, Aug. 18. 365–368, Aug. 25, and pp. 415–419, Sept. 8, 1902.)

Experiments were made with a specimen 2 metres long and 1 decimetre square in section, having four wires of total section 113 square millimetres, one near each corner; the mixture being in the proportion of 3 of Portland cement to 4 of sand. Before loading, the wires are in compression and the concrete in tension, on account of the shrinkage of the latter; after passing the yield point of the concrete, the autographic diagram is practically a straight line parallel to the load due to extension of the iron wires, the force contributed by the former being practically constant for a considerable range of extension. The total load applied was 3,800 kilograms, the strength of the concrete alone being about

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one-third of this. There is also a theoretical investigation of the gain in resistance to compression by having a steel wire embedded in the concrete, together with an account of some experiments on the same.

H. R. C.

Calorimetric Measurement of High Temperatures. R. Ferrini.

(Rivista Sci.-Industriale, 34, pp. 113–114, Aug.–Sept., 1902.)

The author has collected the following data for use in the calorimetric measurement of high temperatures :—

Final Temperature.	Calories absorbed by a Kilogram of		Final Temperature.	Calories absorbed by a Kilogram of Platinum.
	Platinum.	Nickel.		
°C.				
100	3·23	12·0	1,100	42·13
200	6·58	24·0	1,200	46·65
300	9·95	37·0	1,300	51·35
400	13·64	50·0	1,400	56·14
500	17·35	63·5	1,500	61·05
600	21·18	75·0	1,600	66·08
700	25·13	90·0	1,700	71·23
800	29·20	103·0	1,800	76·50
900	33·39	117·5	..	..
1,000	37·70	134·0	..	..

The following simply-derived formula may be used with the table : $T = (1+Q)/13$, where Q is the number of calories required to heat the detached metal from 0° to T°.

D. H. J.

Some Thermal Properties of Naphthas and Kerosenes.

A. H. Gill and H. R. Healey.

(Technology Quarterly, 15, pp. 74–80, March, 1902.)

In the present paper the authors communicate the results of several experiments on the specific heat, heat of combustion and vapour density of some of the lighter petroleum oils used for fuel purposes. The oils studied were the so-called 76° Bé. and the 62° Bé. naphthas, and 135° and 150° fire test kerosenes. In the determinations of the specific heat attention is drawn to the considerable variation of this factor with the temperature. The following table gives the values of the specific heat and of the heat of combustion :—

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	Specific Heat.		Heat of Combustion.	
—	10°–30°	20°–30°	Calories per Gram.	B.T.U. per lb.
76° Naphtha	0·5354	0·5555	10·04	18,080
62° „	..	0·5045	9·92	17,860
135° Kerosene	0·4758	0·4961	9·89	17,810
150° „	..	0·4912	10·10	18,290

A. F.

The Incandescent Mantle. A. H. White and A. F. Traver.

(Soc. Chem. Ind. Journ. 21, pp. 1012–1017, August 15, 1902.)

The temperatures of the flame and mantle are here investigated and the relation between temperature and illumination is examined. Le Chatelier thermo-couples were employed, and a correction for heat lost by radiation from these was arrived at by taking temperatures for different diameters of wire, and then proceeding (by continuing the curve) to the infinitely thin wire. The conduction and correction losses are also eliminated, so that the thermo-couples gave with great certainty the temperatures of the mantles they were in contact with. Tables of figures and curves are given, showing for various mantles the inside temperature, outside temperature, heat conveyed to unit area of mantle per hour, heat conveyed from unit area per hour, heat transformed, illumination per unit area. The temperature of the commercial mantle is from 1,500–1,600°. For different mantles the illumination depends in a greater degree upon the composition than upon the temperature of the mantle. The efficiency of the mantle is due to a solid solution of the oxide of cerium in the oxide of thorium, and this substance is capable of transforming the heat of the flame into light more economically than a black body or any other substance yet known.

J. W. P.

Magnetic Properties of Alloys of Iron. W. Barrett, W. Brown, and R. A. Hadfield.

(Roy. Dublin Soc., Trans. 8, pp. 1–22, Sept., 1902.)

Some of the same ground has been traversed in a previous paper, but fuller details are now given. The chemical analyses, annealing and magnetic measurements, seem to have been conducted in a most exhaustive and thorough way. There are two parts to the paper. (1) Alloys nearly or quite non-magnetic.

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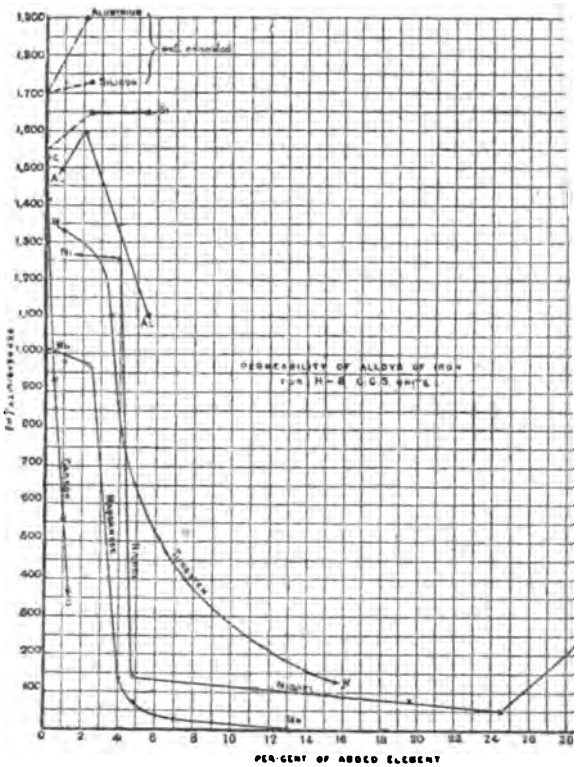
A table given by the authors shows how the intensi field varies with the composition. Small percentages or nickel added to iron cause an enormous drop in perr if they both are added to iron the result is even n High manganese and high nickel-and-manganese peculiar properties, acting in an exactly opposite wa steel as regards annealing and quenching after he there seem possibilities of obtaining a steel of high ter



easily machined, and yet non-magnetic. The con portance of such a substance is obvious, *e.g.*, in non- ships, clocks, watches, etc. (2) Alloys more magne iron. There are two classes, the silicon and alumi the latter have the more extraordinary properties. per cent. of aluminium is included the alloy has μ field 0·5 C.G.S., whereas for the same field the value iron is $\mu = 2{,}500$. The extraordinary magnetic soft alloys is shown by the following table :—

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Swedish iron	35, reversed	15
Silicon-iron alloy	68, „	58
Aluminium-iron alloy	90, „	90

Thus when the rod of iron is placed vertically in the earth's field the deflection of the magnetometer near it is 35; on reversing the rod without any jar the deflection is 15 in the same direction, and so on for the other rods. Now for these rods, whose length is over 400 diameters, the demagnetising factor is negligible; hence the aluminium alloy is seen to be magnetically wonderfully soft. As regards hysteresis losses, it is found that both the silicon and aluminium alloys are economically much superior to iron or to "Lohy" iron, which is a substance specially used in transformers. As to explanation, the authors suggest that as silicon and aluminium have special affinity for oxygen they may reduce the iron into a specially pure state or else absorb occluded gases and so render the material less honeycombed with vesicles.

P. E. S.

Magnetostriction of Steel, Nickel, Cobalt, and Nickel Steels.

H. Nagaoka and K. Honda.

(Philosophical Magazine, 4, pp. 45-72, July, 1902.)

In the author's former experiments the nickel ovoid used was not quite homogeneous, and the cobalt ovoid was imperfect. The present experiments were made to study magnetostriction in more homogeneous metal, in cobalt, both cast and annealed, and in nickel steels. The results are summarised as follows:—The magnetisation of cast cobalt is nearly double that of the annealed; the latter has a high differential susceptibility. The magnetisation of 46 per cent. reversible nickel steel is between iron and cast cobalt, while that of 36 per cent. nickel is nearly the same as in cobalt. That of 29 per cent. nickel is nearly half that of nickel, and 25 per cent. nickel steel is only feebly magnetic. The course of the magnetisation curve of nickel steel resembles that of nickel. In cast cobalt, mechanical elongation in the direction of magnetisation produces diminution of magnetisation in low fields, which gradually lessens as the field strength is increased. Ultimately there is increase of magnetisation by elongation. Thus there is a critical point in cobalt which is opposite in character to the Villari point in iron. In annealed cobalt, mechanical elongation in the direction of magnetisation produces diminution of magnetisation, which increases with the field. In nickel steel mechanical elongation produces increase of magnetisation. Cast cobalt contracts in low fields up to $H = 130$, returns to its original length at $H = 740$, and then elongates slowly. Annealed cobalt contracts without showing a minimum up to $H = 1{,}800$. These effects stand in reciprocal relation with the effect of mechanically elongating cobalt.

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Nickel steel elongates by magnetisation. The character of the change is similar to that in nickel, but the sense is different. The rate of change in high fields is greater in 29 per cent. nickel than in 36 per cent. nickel, in which it is again greater than in 46 per cent. nickel. Nickel steel elongates to a greater degree in the annealed than in the hard-drawn state. Iron, steel, nickel and nickel steel increase in volume by magnetisation, but cobalt contracts. Cast cobalt contracts rapidly in low fields, reaching a minimum at $H = 900$, after which it expands. Annealed cobalt contracts continuously as the field increases. The increase of volume in nickel steels is almost proportional to the field. The increase becomes greater as the percentage of nickel is less. The increase in 29 per cent. nickel is nearly 40 times that in iron. The twist produced by the combined action of circular or longitudinal magnetisation in iron, nickel and nickel steel increases with the longitudinal field strength, and reaches a maximum. The sense of twist in iron and nickel steel is opposite to that in nickel. The reciprocal effect holds.

G. H. B.

Furnaces Electrically Heated by Means of Platinum Foil.

E. Haagn.

(Zeitsch. Elektrochem. 8, pp. 509–511; Discussion, p. 512, July 31, 1902. Paper read before the German Electrochemical Society at Würzburg, May 9, 1902.)

This mode of applying resistance-heating by means of platinum foil surrounding the object to be heated, according to the author offers advantages over wire applied in the same manner, as it is cheaper and more efficient. A temperature of 1,700° C. was reached, at which point porcelain tubes surrounded by the platinum foil softened. The author further enumerates the various uses these furnaces can be put to. Useful information as to prices, dimensions, current consumption, and temperature obtainable is given at the end of the paper.

O. J. S.

Efficiency of Non-conducting Compositions. T. H. Beare.

(Mech. Eng. 10, pp. 391–392, Sep. 20, 1902. Abstract of a paper read before the Royal Scottish Society of Arts.)

The experiments referred to—extending over three years—were carried out with wrought-iron steam piping 8 feet $10\frac{5}{8}$ inches long and 3·53 inches mean external diameter, average thickness of metal being $\frac{1}{4}$ inch. Total area of external surface of the uncovered pipe was 8·132 square feet.

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SUMMARY OF RESULTS.

Kind of Covering.	Thickness of Covering. Inches.	Weight of 1 Cubic Foot of Covering Loose. Lbs.	Weight of 1 Cubic Foot of Covering on Pipe Dry. Lbs.	Steam-pressure by Gauge. Lbs. per Square Inch.	Temperature, Fahr.			Loss of Heat.	Condensed Steam.
					Steam in Pipe.	Air in Room.	Outside of Covering.	B.T.U. per Sq. Ft. External Surface, uncovered Pipe per Hour.	Lbs. per Sq. Ft., External uncovered Surface per Hour.
Series A.									
Uncovered pipe	..	..	..	3·0	223	64·5	..	360·3	0·376
„ „	..	..	..	59·0	306	62·4	..	697·0	0·775
Series B.									
Uncovered pipe	..	..	..	46·5	294	94·0	..	564·0	0·622
Asbestos, No. 1	1·42	39·0	49·8	45·0	292	61·9	125·0	213·3	0·235
„ No. 2	1·39	..	..	45·0	292	59·3	115·0	182·9	0·202
„ No. 3	1·42	28·6	38·9	45·0	292	56·8	108·0	172·1	0·189
„ No. 4	1·54	22·7	33·6	46·0	293	65·0	..	134·0	0·148
„ „	1·43	22·7	33·6	47·0	294	68·5	116·0	147·3	0·162
Fossil meal composition	1·40	73·8[2]	47·5	44·0	291	61·3	112·0	182·1	0·201
Patent non-conducting composition	1·38	22·5	38·3	47·0	294	63·7	120·0	168·9	0·186
Series C.									
Uncovered pipe	..	..	..	80·0	324	66·0	..	767·0	0·866
„ „	..	..	..	86·0	328	68·3	..	775·0	0·878
Asbestos, No. 1	1·42	39·0	49·8	70·0	323	59·9	132·0	262·4	0·295
„ „	1·50	..[1]	..[1]	80·0	324	61·0	135·9	202·6	0·229
„ No. 2	1·39	..	..	76·0	321	60·7	123·0	221·4	0·250
„ No. 3	1·30	..[1]	..[1]	83·0	327	67·0	116·0	163·5	0·185
„ „	1·42	28·6	38·9	79·0	323	59·4	119·0	192·0	0·217
„ No. 4	1·54	22·7	33·6	79·0	323	66·2	..	168·3	0·190
„ „	1·43	22·7	33·8	80·0	324	62·6	118·0	180·9	0·204
Fossil meal composition	1·30	..[1]	..[1]	81·0	325	79·0	140·8	232·0	0·262
„ „ „	1·40	73·8[2]	47·5	78·0	322	65·6	130·0	207·5	0·234
Patent non-conducting composition	1·38	22·5	38·3	80·0	324	64·1	130·0	192·0	0·217
Mica sectional covering	1·14	..[1]	..[1]	80·0	324	80·0	114·3	134·7	0·152
Series D.									
Uncovered pipe	..	..	..	135·0	358	67·0	..	903·0	1·050
Asbestos, No. 1	1·50	..[1]	..[1]	149·0	365	62·0	131·8	271·7	0·318
„ No. 3	1·30	..[1]	..[1]	137·0	359	75·0	120·0	208·0	0·242
Fossil meal composition	1·30	..[1]	..[1]	134·0	358	78·0	163·0	252·5	0·293
Mica sectional covering	1·14	..[1]	..[1]	130·0	355	79·0	119·4	150·3	0·174

[1] In the case of these experiments the weight of the covering when dry upon the pipe per square foot of external surface of pipe uncovered was determined by careful measurement and weighing. The results are as follows:—

Asbestos, No. 1	10·2	lbs. per square foot of pipe-surface	
„ No. 2	7·4	„	„
Fossil meal composition	8·24	„	„
Mica sectional covering	4·73	„	„

[2] Wet.

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The durability of the various coverings was not tested, time and practical experience being required to determine this factor. Regarding the heat losses per degree of difference of temperature between steam and air, the author points out that the uncovered pipe experiments—excepting those at 3 lbs. steam pressure—show an average of 2·96 B.Th.U. per square foot of external surface with the thickness of pipe used. For the usual thicknesses this may be taken at three, and heat loss may be readily calculated for any area and steam pressure. For the mica sectional covering of the thickness employed, the average loss works out at 0·548 B.Th.U. per square foot of surface. For Asbestos No. 4 the average loss with thickness of 1·54 inch is 0·621 B.Th.U., and for a thickness of 1·43 inch the loss is 0·672 B.Th.U. For Asbestos No. 1, with 1·5 inch thickness, the loss is 0·833 B.Th.U., and 1·42 inch thickness the loss averages 0·962 B.Th.U., a difference of less than $\frac{1}{10}$ inch showing a considerable difference in the amount of loss.

F. J. R.

Steam-Pipe Covering. H. G. Stott.

(Elect. World and Engineer, 40, pp. 854–856, Nov. 29, 1902. Abstract of a paper read before the 23rd Convention of the Association of Edison Illuminating Companies, held at The Mount Washington, N.H., September 9, 10, and 11, 1902.)

In order to determine the best means of covering steam pipes for the Manhattan Railway Company's power-house, 200 feet of 2-inch iron pipe was coupled in series and connected with a 250-kilowatt dynamo, together with measuring instruments. Lengths of 15 feet were marked off and fitted with potential wires 2 feet from each end; these lengths were then covered with various types of covering, the resistance of each section and the temperature coefficient determined, and the whole length of pipe

Heat Saved by Covering Steam Pipes.

Covering.	B.T.U. lost per Square Foot at 160 Lbs. Pressure.	Per Cent. Heat saved by Covering.
85 per cent. magnesia: sectional	2·060	84·2
Solid cork: sectional	2·170	83·3
Laminated asbestos cork: sectional	2·395	81·6
Asbestos air cell (indented): sectional ("Imperial")	2·465	81·0
Asbestos sponge felted: sectional	2·683	79·4
Asbestos air cell (long): sectional	3·380	74·0
"Asbestocel" (radial): sectional	2·920	77·5
Asbestos air cell (long): sectional	3·015	76·8
"Remanit" (carbonised silk) wrapped	1·708	86·9
Bare pipe (from outside tests)	13·000	..

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heated by electric current to about 370° F. for three days to dry the coverings. The tests were carried out at various temperatures, the current being kept on for about ten hours before taking readings in order to allow the temperatures to become steady. From the watts lost in each section the rate of loss of heat was calculated; repeated tests agreed within 2 per cent. The Table on p. 431 shows some of the results for a thickness of about 1·125 inch.

The efficiency of magnesia was found to vary directly as the square root of the thickness. A table is given showing the relative values of the first cost and the heat loss for different thicknesses and various periods, from which it appears that the thickness of covering should be determined with regard to the intended duration of the installation, and is an important consideration.

A. H. A.

Flywheel capacity of Engine-Driven Alternators.

W. I. Slichter.

(Amer. Soc. Mech. Engin., Trans. 24, No. 0967, pp. 1–13, 1902.)

In this paper the author classifies and discusses the causes of cyclical speed variation of engines, and gives as an approximate formula for the displacement of the crank-pin from the mean position the equation $A = \frac{k \times P \times g \times 360}{W V_0^2 \times 4\pi r}$ where k is the "unbalancing factor," or the ratio of the maximum unbalanced energy (which goes to accelerate the flywheel) to P, the total foot pounds of energy per revolution, W is the effective weight and V_0 the mean speed of flywheel, g the gravity constant 32, and N the number of impulses per revolution. The value of k may be from 0·15 to 0·30. For flywheel alternators the value of A must be multiplied by the number of pairs of poles to give the displacement from the mean in the electrical circuit. The maximum allowable value for this quantity is about 2·5, if the maximum cross current is to be limited to 10 per cent. of full load current; with a greater displacement parallel running, while it might be quite possible under favourable conditions, such as low resistance between generators and few synchronous motors in circuit, would be difficult or impossible under more exacting conditions. The "synchronising torque" of the generators is proportional to the displacement (in alternating plants), and occurs simultaneously with, and increases the effect of, the excess effort of the engine. (In direct-current plants the curve of torque, which is proportional in this case to speed, and not to displacement, is shifted 90° from the curve of genuine effort, which it merely distorts). The formula proposed by the author for determining the effective flywheel weight based upon a maximum displacement of 2·5 is Wr^2

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$= 10^9.KW.C/S^4$, where W is the weight required, r the radius of gyration, KW the rating of the generator, S the number of revolutions per minute, and C a constant directly proportional to the periodicity and having for 50 periods the values 630, 550 and 500 for horizontal single crank, vertical compound, and horizontal compound engines respectively. The weights calculated by this formula are found to give reasonable values so far as hunting and parallel operation are concerned, though it may be sometimes necessary for special reasons, *e.g.*, in railway power stations, to increase the weight immensely and to ignore the angular displacement. Lastly the question of hunting is referred to, and the remedies pointed out—dash-pot governors or "amortisseurs." The paper is illustrated with curves showing the actual performance of an 800-kilowatt compound engine and alternator set; a noticeable feature being the combined curve of high-and-low-pressure crank efforts which shows practically only two impulses per revolution.

B. P. S.

Asynchronous Polyphase Generator. L. GRATZMULLER.

(Ind. Elect. 11, pp. 437–439, Oct. 10, 1902.)

The author employs a new principle for making an alternator self-exciting. When we have a direct-current ring-wound armature rotating in a bipolar field, if we make the brushes rotate in the opposite direction to the armature, then if they be connected by choking coils the armature reaction of the alternating current generated will have a component in the direction of the resultant magnetic flux. Consider now an induction motor having its stator wound for polyphase currents. Replace the rotor by a continuous-current armature having as many brushes on the commutator as there are phases in the stator. Then if these brushes are connected star or mesh fashion by choking coils, we can by driving the rotor make the machine into a self-exciting alternator, the principle used being that given above. The author has verified that a machine made in this way is self-exciting.

A. R.

New Rotary-Converter Distribution.

(West. Electn. 31, pp. 290–291, Oct. 25, 1902.)

The paper describes a system devised by C. P. Steinmetz and L. R. Emmet, the general connections of which are shown in Fig. 1. The secondaries of the two transformers, T_1 and T_2, are suitably interconnected, and their windings so proportioned that two two-phase systems are produced, the vector diagram for one

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being T and for the other ⊥. Fig. 2 is a vector diagram showing how these two systems are combined to form a six-phase source of potential, suitable for feeding a rotary converter. The arrangement may be extended to converters having a number of phases represented by a multiple of 3. The neutral point N (terminals 14 and 15, Fig. 1) gives a convenient neutral connection for a three-wire direct-current supply from the rotary.

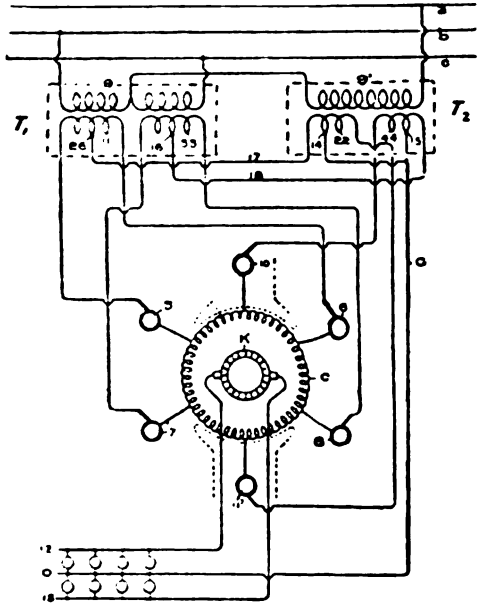

Fig. 1. NEW ROTARY-CONVERTER DISTRIBUTION SYSTEM.

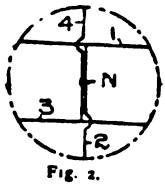

Fig. 2.

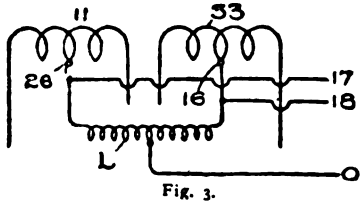

Fig. 3.

As difficulty may be experienced in connecting straight on to such points in the windings as 14 and 15, the authors suggest a subsidiary device, which is diagrammatically depicted in Fig. 3. [The transformer connections are similar to those employed by Scott for the conversion of two-phase to three-phase current, and the neutral connection has some similarity to the three-wire direct-current compensator of Dobrowolski.]

R. C. R.

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Sub-Station of the Chicago Edison Company.

(Elect. World and Engineer, 40, pp. 849–853, Nov. 29, 1902.)

In this paper the plant and arrangement of Randolph Street sub-station of the Chicago Edison company are described. It has been recognised that in this part of Chicago the limit of direct-current transmission has been reached, even with a power-station comparatively near the load-centre of a congested district, and the system considered standard when the station was planned ten years ago has, therefore, been abandoned in favour of rotary converter sub-stations. The Randolph Street sub-station is in the basement of a 21-story fire-proof office building and is laid out for twelve 270-volt rotary converters, each of 500 kw. capacity, of which five are already installed. Each has a bank of three transformers mounted in sets of six over air chambers and cooled by centrifugal blowers. The primary voltage on the transformers is 9,000 and the range afforded is from 240 to 270 on the direct-current bus-bars. The regulators are adjustable either by hand or by small induction motors to minimise the risk of breakdown. Three sets of three-phase mains enter the station at different places, coming from the same or different generators in the power-station by different routes. Each set of mains is connected by oil switches to bus-bars supplying. also through oil switches, the primaries of transformers of four of the rotaries; if necessary, the various bus-bars can be coupled in parallel. The direct-current leads from the rotaries to the switch-boards are also isolated as much as possible so that a short circuit in one of the trenches in which they are run could not cripple more than two converters. A full description is given of the twelve switchboard panels, one for each rotary, which contain both high and low-tension control switches. Red and green pilot lamps show whether the switches are open or closed; the high-tension switches have overload tripping relays. A Lincoln synchroniser is used for paralleling the rotaries. Any want of balance of the load on the two sides of the system is at present adjusted at the generating station, but a 100-kw. 125-volt rotary is provided to be used in future on either side of the system as required. By means of a relay worked by a contact on the pointer of a central zero ammeter in the leads from the direct-current bus-bars to the converters, a circuit breaker is operated when a current in excess of 500 amperes flows from the machine; in starting, however, the position of the fixed contact is such that the use of 1,000 amperes in the reverse direction is allowed. The direct-current ammeters are not provided with the usual cumbersome shunt resistances, but current for them is tapped off from two points on the cable at a suitable distance apart. Compensation for temperature error is made by a coil of fine copper wire surrounding the cable and put in series with the ammeter. The marble slabs of which the switchboards are made are not mounted directly on the angle-iron frames, but are separated

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from the latter by insulating distance pieces 3½ inches thick, the permits of the circuits being run much more neatly and safely than if they had to be carried over the iron frame. The sub-station is ventilated by fan-blowers. As the Chicago Edison company is constantly increasing the number of its sub-stations (the growth for the current year being about 49 per cent.), and the Harrison Street generating station being now full, a new power-station of 100,000 kilowatts capacity is now being put down. The supply will be 25-cycle, three-phase, 9,000-volt current for transmission to sub-stations, which will transform some of them to direct current as described above, and others to 60-cycle, 4,000-volt, three-phase, so as to work in with the supply given by the Commonwealth Electric company.

B. P. S.

Electric Installation of the "Société Hydro-Electrique de Fure et Morge."

(Ind. Elect. 11, pp. 487–498, Nov. 10, 1902.)

The undertaking described is the water-power electric installation erected by the "Société Hydro-électrique de Fure et Morge," 15 kilometres distant from Grenoble, deriving motive power from the river Drac and supplying electric energy to the industrial valleys of the Fure and the Morge, from which the Society takes its name. The hydraulic works are for the most part of the general type. The conduit leading to the turbines is 4,600 metres long, the first part (2,100 metres) being of armoured cement and the remainder (2,500 metres) of sheet steel. The whole conduit rests on a concrete foundation, 30 cubic metres thick under the armoured-cement pipe and 50 cubic metres thick under the steel pipe, and all buried in the ground. By this method of resting the metal conduit of large diameter (330 cubic metres) upon a cradle of cement buried in the ground—a method adopted here for the first time—the great advantage is gained of preventing deformation of the pipe during the delicate operation of filling, and excellent results have been obtained. This conduit is supplied with three stacks at intervals along its length, two of armoured cement and one at the very end of sheet steel, which, by providing an outlet, prevent the battering action of the water in the event of a sudden stop of the turbines. The head of water obtained, allowing for losses in the pipes, is 32 metres, and as the amount used is 17 cubic metre per second, the hydraulic power in the hood of the turbines is 7,200 HP. In the power-house the generating sets are in a hall 44 metres long and 12 metres broad, with a 15-ton overhead crane. Directly underneath the floor of this hall is a gallery containing the cable from the generators to the switchboard. There are in the main hall five turbines, each of 1,350 HP., connected to alternators; two

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turbines, each of 150 HP., for the exciting generators; and one 5-HP. turbine which feeds the hydraulic accumulators necessary for the operation of small pilot-motors provided for actuating the sluice-valves controlling the water-supply to each of three of the main turbines. Each turbine is directly coupled to a Brown-Boyer three-phase alternator, generating current at 3,000 volts at 3,000 revolutions per minute with a frequency of 50 perds per second. The output of each alternator on an inductive circuit of power-factor 0·8 is 950 kilowatts. Each generator can supply 225 amperes per phase with power-factor 0·8, and 180 amperes with power-factor 1. The exciting generators are of capacity 100 kilowatts and supply continuous current at 110 volts. One is held as reserve, while the other excites the field windings of the alternators and supplies energy for the lighting of the buildings. The voltage of the alternators is transformed to 26,000 volts by step-up oil-cooled transformers placed in another room in the basement. They are so designed that by a simple change of connections the transformation may be made either from 3,000 to 15,000 volts, or from 3,000 to 26,000. The primary has a mesh-winding; the secondary may be connected either in mesh or in star according as the line voltage desired is 15,000 or 25,000. On a balcony overlooking the generators is placed the switchboard, which receives only low-tension currents, but from it the switches for the 3,000-volt lines, which are placed in an enclosed space under the balcony, can be operated by chain-gearing. The switches and fuses and all other apparatus bearing the line voltage are placed behind this main switchboard, where are also found the lightning arresters for the protection of the line. The transmission is by overhead wires extending to various towns in the district. The principal centres are Moirans, Voiron, Rives, Charavines, Fures-Tullins. Moirons, to which the lines are first led, is about 35 kilograms distant from the generating station. The voltage chosen—26,000 volts—is the highest actually in use in Europe. 3,500 kilowatts are transmitted to Moirons, and from there about 1,300 kilowatts are conveyed to Voiron and about 1,600 kilowatts to Rives. As these districts are already supplied with lighting installations, all the energy is sold for power-supply. The industries are diverse in character, including paper factories, mills, collieries, and silk factories, and as most of these require a constant speed of motor irrespective of the load, which often changes suddenly and very considerably, it was decided to use only asynchronous motors. The users may have supply at 1,000 volts or at low-tension, and according to the choice the transformation from the line voltage is performed at one operation or in two steps. The ratio of transformation adopted is 26,000 to 2,000, or 26,000 to 1,000, but one transformer of 150-kilowatt capacity transforms directly from the line voltage to 120 volts. There are eleven main sub-stations, and the transformers are of three types—500, 300, and 150 kilowatts. Where double transformation is made, the second transformer is placed on the premises of the user, as near as possible to the motors to be supplied. These transformers are of 100, 50, and

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30 kilowatt capacity. The price charged to consumers for power is £6 per HP. per annum for continuous use, but the rate varies for intermittent use.

W. C. H.

Valtellina Railway. Fumrro.

(Elettricità, Milan, 21, pp. 691–714, Nov. 2, 1902.)

The application of electric traction to the line from Lecco to Sondrio is a preliminary experiment with a view to much more extensive applications to the Italian railways, which may, at an early date, be worked directly by the Government instead of being leased, as at present, to companies. The fall at the power-station is 30 millimetres, with a minimum flow of 25 centimetres per second. There is a canal 4,800 millimetres long, having 15 tunnels, of which the longest is 770 millimetres long. The canal is 4 metres wide at the bottom; the sides have a batter of 1 in 10, and the wetted section is 10 square metres. The sides and bottom are lined throughout with cement to prevent loss by filtration and to facilitate the flow. The fall in the canal is 1 in 1,000. From the end of the canal the water is carried through two pipes, each 2·5 metres in diameter and 68 metres long, inclined at an angle of 45 degrees. Each pipe line feeds two turbines which are overhung on the alternator shafts. There are three alternators of 2,000 HP. each and one of 3,000 HP., all running at 150 revolutions per minute. The turbines are of the Francis type and were built by Ganz & Co. The alternators, built by Schukert & Co., have external fixed armatures and 12-pole rotating field. They work at a tension of 22,000 volts. The exciters are direct-coupled, but are themselves excited from a small auxiliary dynamo and turbine. The external diameter of the alternators is 5 metres; they weigh 70 tons, the weight of the rotating part being 44 tons. The switchboards, also built by Schukert & Co., contain high-tension switches of the "horn" type—similar to the lightning arresters which are outside the building. There are also "water-jet" lightning arresters, consisting of a fine jet through which the different lines are connected to earth. *The high tension line* is of 8-millimetre wires from Morbegno to Colico, and of 7-millimetre for the rest of the 90 kilometres over which it extends. It is carried on four-shed porcelain insulators, and is run on the same poles as the trolley line except where the latter passes through tunnels, where it is carried outside. *Transformer stations.*—These are nine in number, the average distance apart being 8 or 9 kilometres. They each contain three-phase transformers for 450 apparent kilowatts stepping down to 3,000 volts. All transformer stations are in parallel on both primary and secondary sides. *The trolley wires* have been calculated for a maximum drop of 5 per cent. in the tension. The two wires are 90 cubic metres apart and are carried

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on bracket poles at 40-metre intervals in the straight track. On curves span wires are used, and the supports are close at 26 metres. Ambroin is used for the suspension insulators and the span wires are further insulated with porcelain.

A. E. L.

Prevention of Electrolysis by Earth Returns. A. Larsen.

(Elektrotechn. Zeitschr., 23, pp. 868–870, Sept. 25, 1902.)

The Author has carried out a series of tests which tend to prove that electrolytic corrosion due to stray currents from tramway circuits may be lessened by periodically reversing the direction of the current. If the current is reversed in direction once a day, the corrosion is reduced to one-fourth of the normal amount; and if the current is reversed once an hour, it becomes about one-thirtieth of the same amount. The experiments which are here more particularly described extended over a period of three months at the beginning of the year 1902. Some cast-iron pipes 9 feet long were cut in two; the diameters of the pipes were in some cases 6 inches, and in others 4 inches. Each length was buried in a separate box together with an iron plate which served as the other electrode, the whole being filled in with a sandy mixture, which consisted of 80·3 per cent. of sand, 0·16 per cent. of soluble matter, including 0·084 per cent. of sulphates and a trace of chlorides, 4·7 per cent. of organic matter, and the remainder consisted of moisture. All the pipes were carefully weighed at the start. One series was exposed to a continuous current, unchanged in direction; these are called the *a*-pipes. The other pipes, exactly similar to the foregoing, were joined up in series with the corresponding *a*-pipes, but by means of a switch the direction of the current through them was periodically changed, in some cases once an hour, in others once a day. This second series is referred to as the *b*-pipes. At the end of the three months the pipes were examined. All the *a*-pipes were found to be much corroded, and had pittings on the surface. The *b*-pipes had only a slight surface of rust in those cases in which the current had been changed hourly in direction; and there was slight corrosion, but no pitting in those cases in which the current had been changed daily in direction. The surfaces of all the pipes were carefully scraped and cleaned, and they were then weighed. After this cleaning the pipes were left exposed to the air for some days, and in the course of ten days the *a*-pipes showed signs of scaling on the surface, particularly round the spots where the pittings had formed; and thus it became evident that the corrosion had extended further than was at first visible to the naked eye. These scales were therefore scraped off and weighed. The results of the experiments are given in the following table:—

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Diameter of Pipe in Millimetres.	Mean Current Strength in Amperes.	Pipe.	Ampere Hours.	Direction of Current Changed.	Loss of Weight in Grammes.	Amount Scaled off in Grammes.	Total.
150	0·301	*a*	608	..	590	265	855
		b	+304 / −304	hourly	27	..	27
100	0·121	*a*	244	..	231	90	321
		b	+122 / −122	hourly	10	..	10
150	0·341	*a*	570	..	508	194	702
		b	+285 / −285	daily	126	38	164
100	0·124	*a*	208	..	202	72	274
		b	+104 / −104	daily	67	3	70

W. H. S.

Some Characteristics of the Flow of Water in Channels of Varying Cross-Section. T. E. Stanton.

(Engineering, 74, pp. 644 and 666, Nov. 21, 1902.)

It was formerly assumed that the loss of head due to friction is the same for a given pipe AB whether the flow be from A to B or B to A, provided that the quantity of flow is the same in the two cases. Reynolds, however, has demonstrated that the loss of energy due to friction is considerably greater in the diverging direction of the tube than in the converging. The object of the Author's experiments was to obtain information on (1) the effect of the form of the channel, and (2) the effect of the angle of divergence on the loss of head involved. The first observations were made on a channel of circular section, 4½ inches long, the diameter decreasing from ¾ inch at one end to ¼ inch at the other. The pressures at the largest and smallest sections for given velocities of flow were carefully measured. The author finds that the loss of head of water flowing as a diverging current to a state in which the kinetic energy is practically negligible is approximately 25 per cent. of the initial velocity head, and that when the direction of flow is reversed the loss is approximately 10 per cent. of the final velocity head; those ratios are the same for the range of velocity 11 feet per second to 30 per second at the least section. In the experiments on the second point, the diverging channel was of rectangular section, ⅜ inch deep, and at the widest part 2 inches broad. The losses of energy calculated from the results show that in a diverging channel of rectangular section the loss of energy is nearly constant for all angles of divergence ranging from 2° up to a certain limiting value, after which it increases rapidly; for the channels used the limiting angle

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is about 6°. For diverging flow in the first (circular) channel, the coefficient of friction is about four times its value for a parallel channel. Finally the author applies his results to the consideration of flow past ship-shaped forms. Complete tables of results are given throughout.

W. S.

Theory of the Welsbach Gas Mantle. M. SOLOMON.

(Nature, 67, pp. 82–84, Nov. 27, 1902.)

The Author reviews the work of several recent investigations on this subject, and concludes that the light emitted is due partly to good radiating power, partly to the high temperature attained by the substance of the mantle, and partly to selective emissivity Armstrong, Welsbach, and others consider that the luminosity is due to chemical changes of an oscillatory nature, which take place in the substance of the mantle, the ceria molecules probably oscillating between a lower and a higher state of oxidation. Welsbach holds that in one or other state of oxidation ceria forms a compound with thoria; reactions of various kinds occurring several million times a second cause molecular shocks, which in their turn give rise to luminous oscillations. Swinburne considers that the light is merely a high temperature effect, a certain quantity of ceria being necessary to increase the radiating power of the mantle. Le Chatelier and Nernst have shown that the emissivity is poor in the region of the red rays, and this tends to raise the temperature of the mantle, which according to Bunte is higher than that of the flame. White, Travers, and Russell have estimated the temperatures by means of thermopiles, and find the mantle to be slightly below the temperature of the flame, a mantle composed of pure thoria being slightly hotter than one composed of 99 per cent. thoria and 1 per cent. ceria.

W. H. S.

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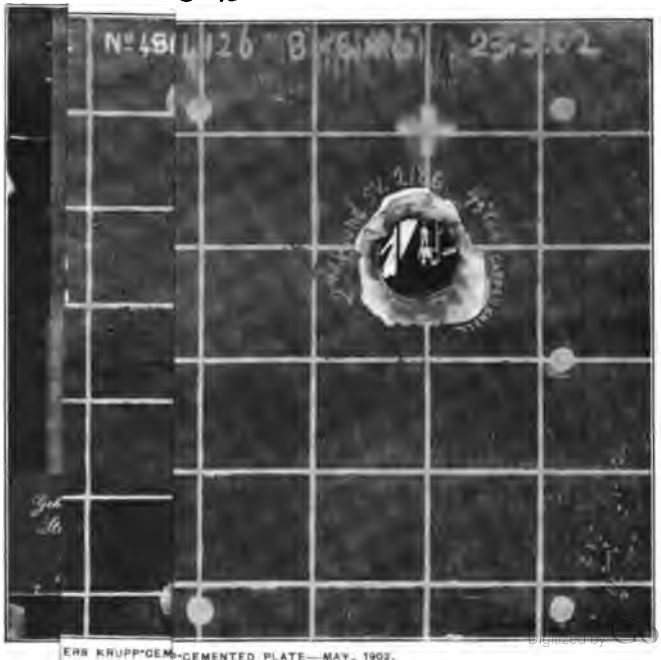
Fig. 44

BETHL 6-INCH ARMOUR-PIERCING SHOT,
ASSING THROUGH A 6-INCH KRUPP-CEMENTED PLATE.

Fig. ig. 43.



ERS KRUPP-CEMENTED PLATE—MAY, 1902.

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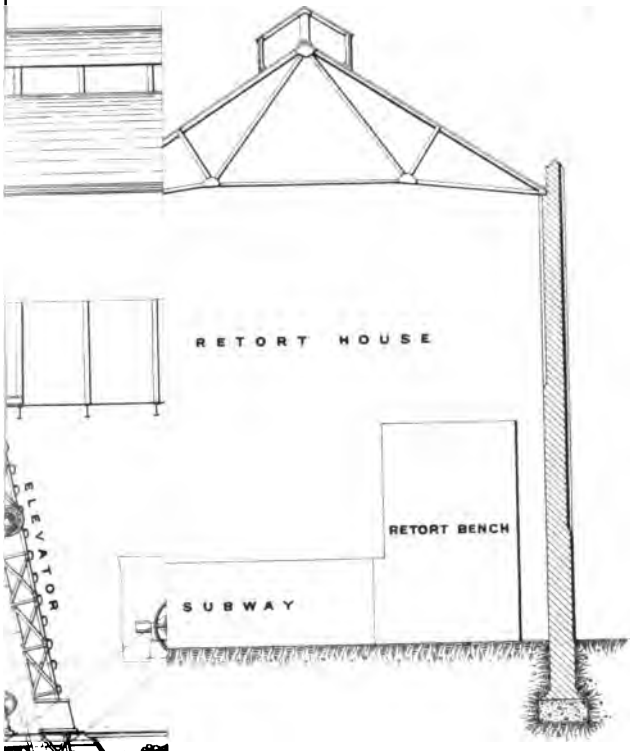

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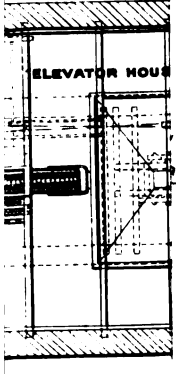

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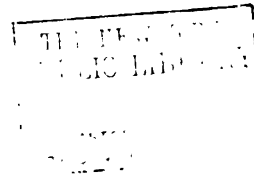

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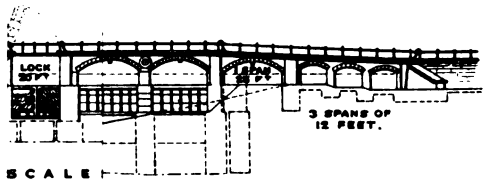

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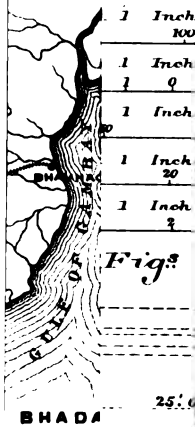

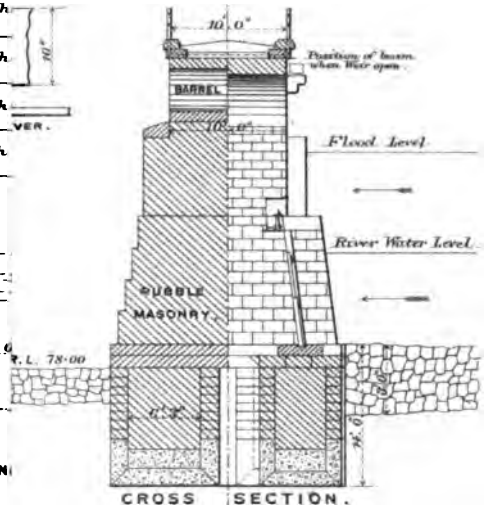

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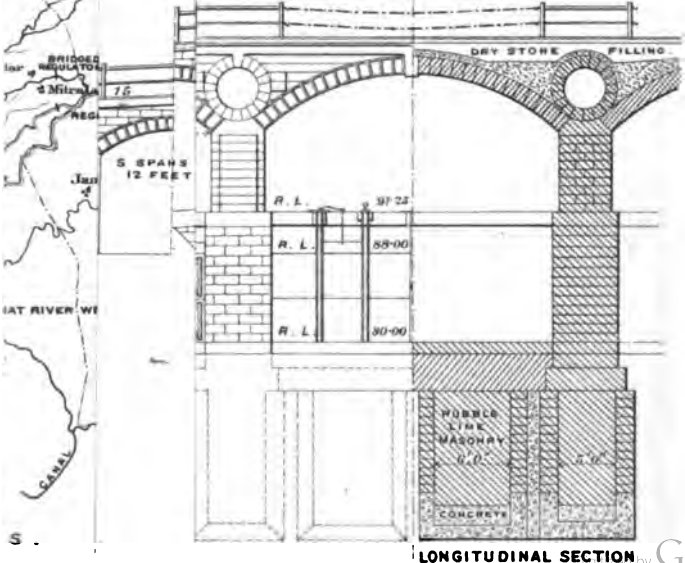
THROUGH PIER. THROUGH ARCH & SILL.



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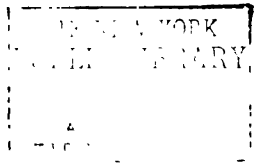

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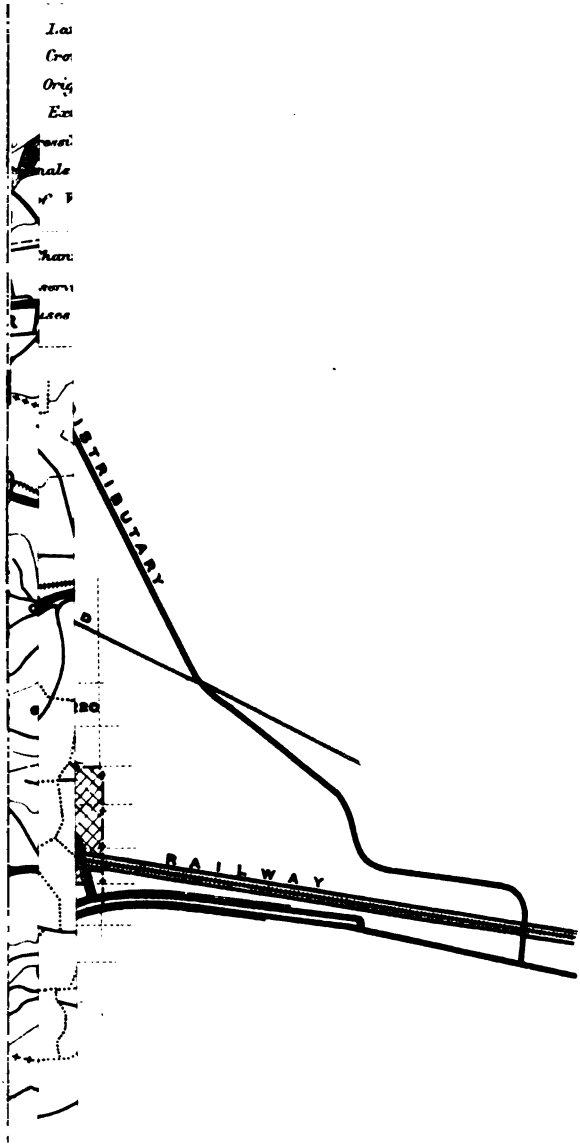

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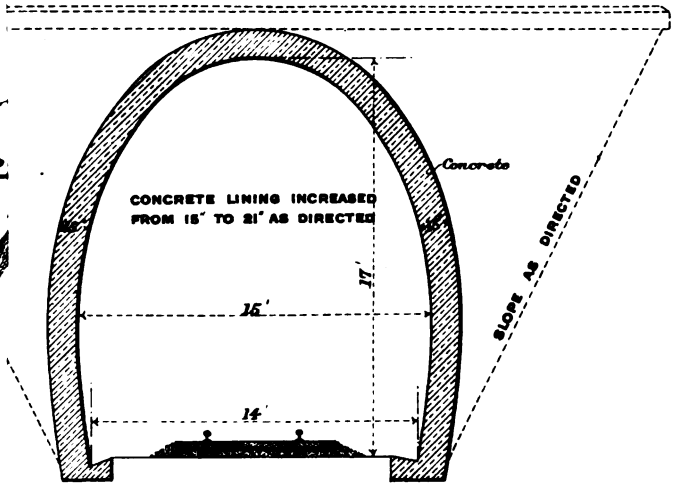
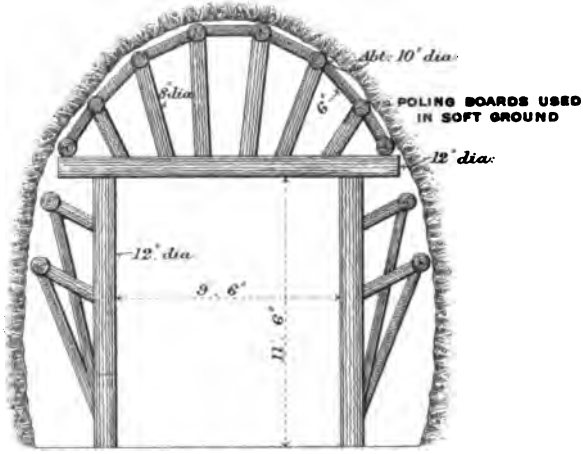


CROSS-SECTION SHOWING CONCRETE LINING ETC., OF TUNNELS



CROSS-SECTION SHOWING METHOD OF SUPPORTING TUNNEL EXCAVATION UPON TIMBERS

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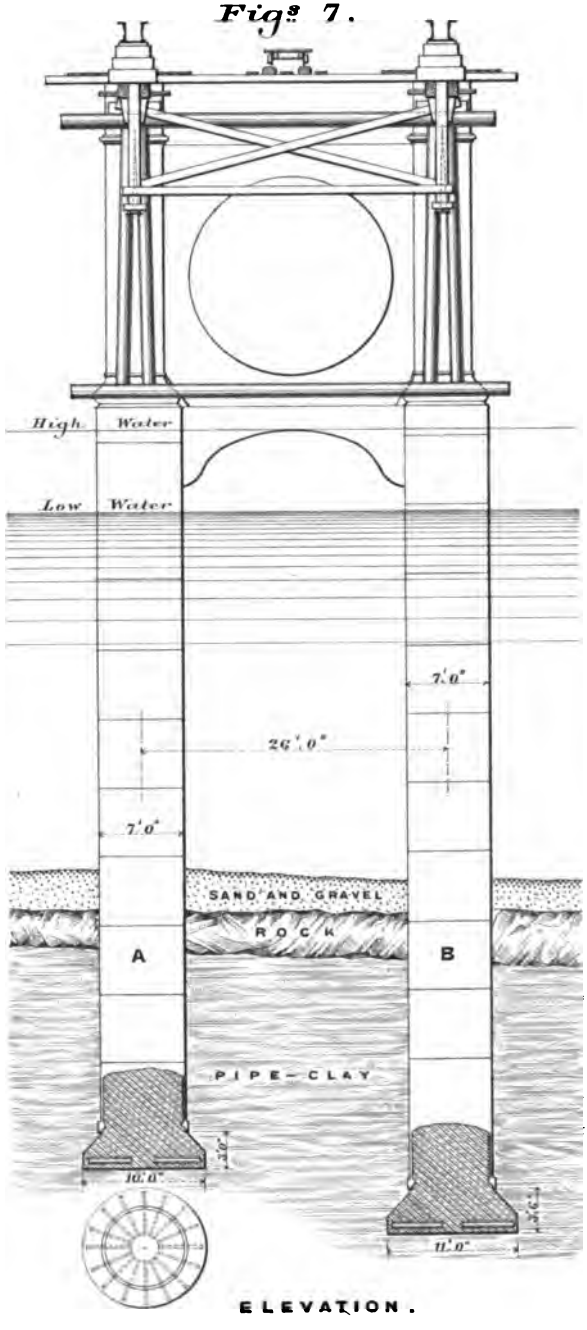

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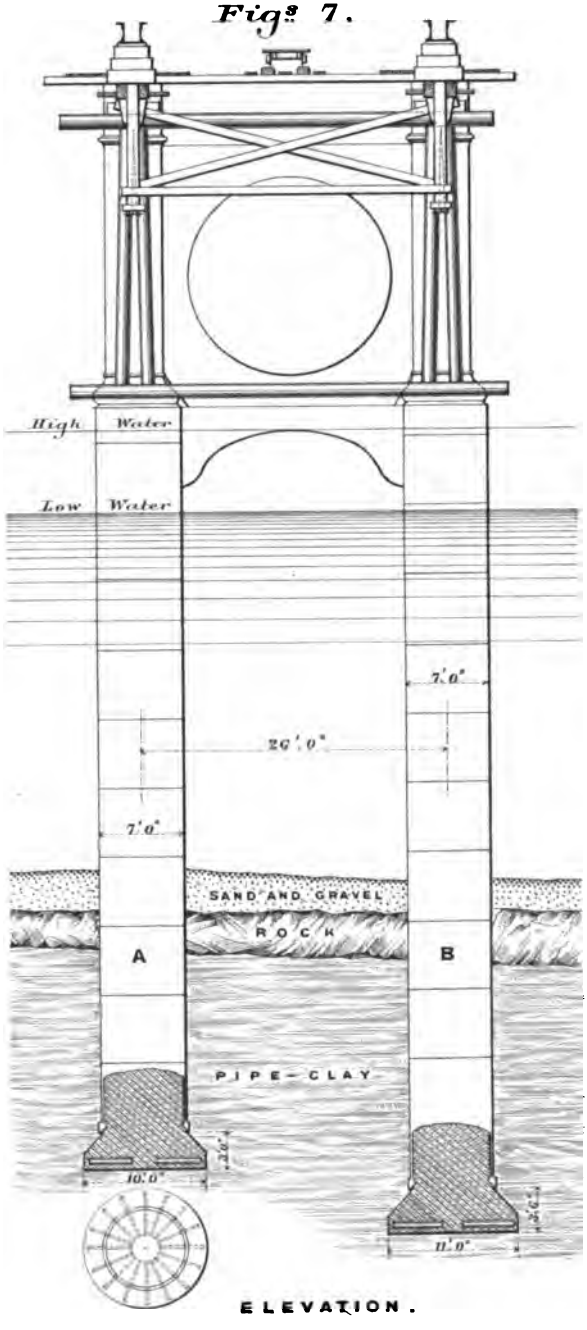

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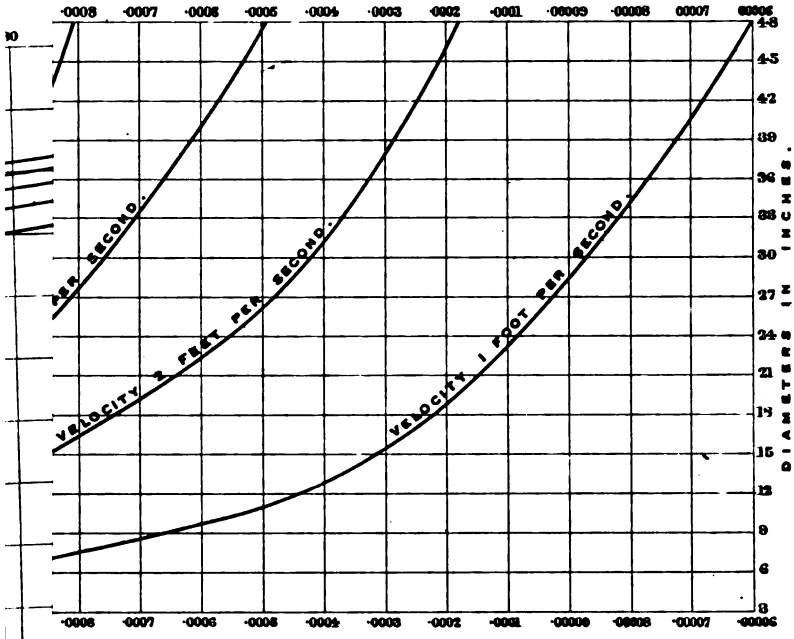

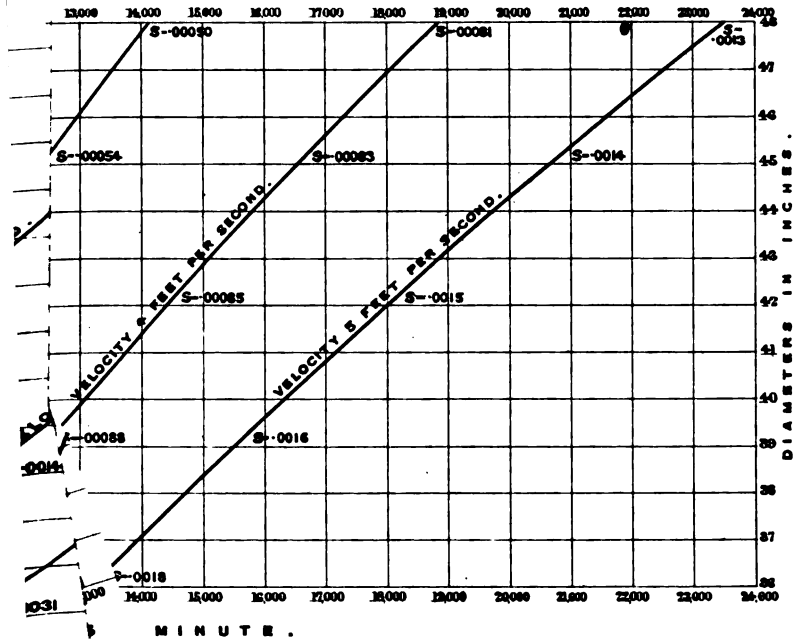

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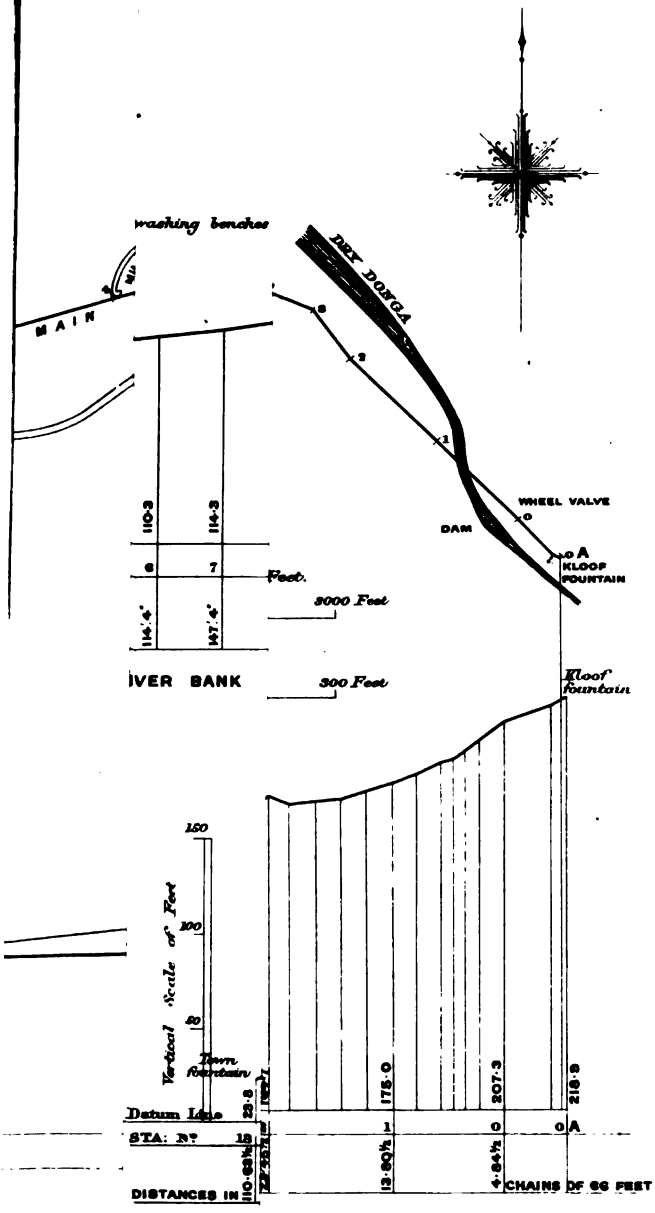

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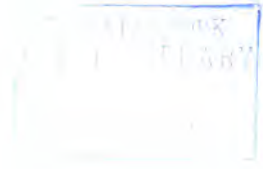

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